APRIL 1955

THE WELDING JOURNAL

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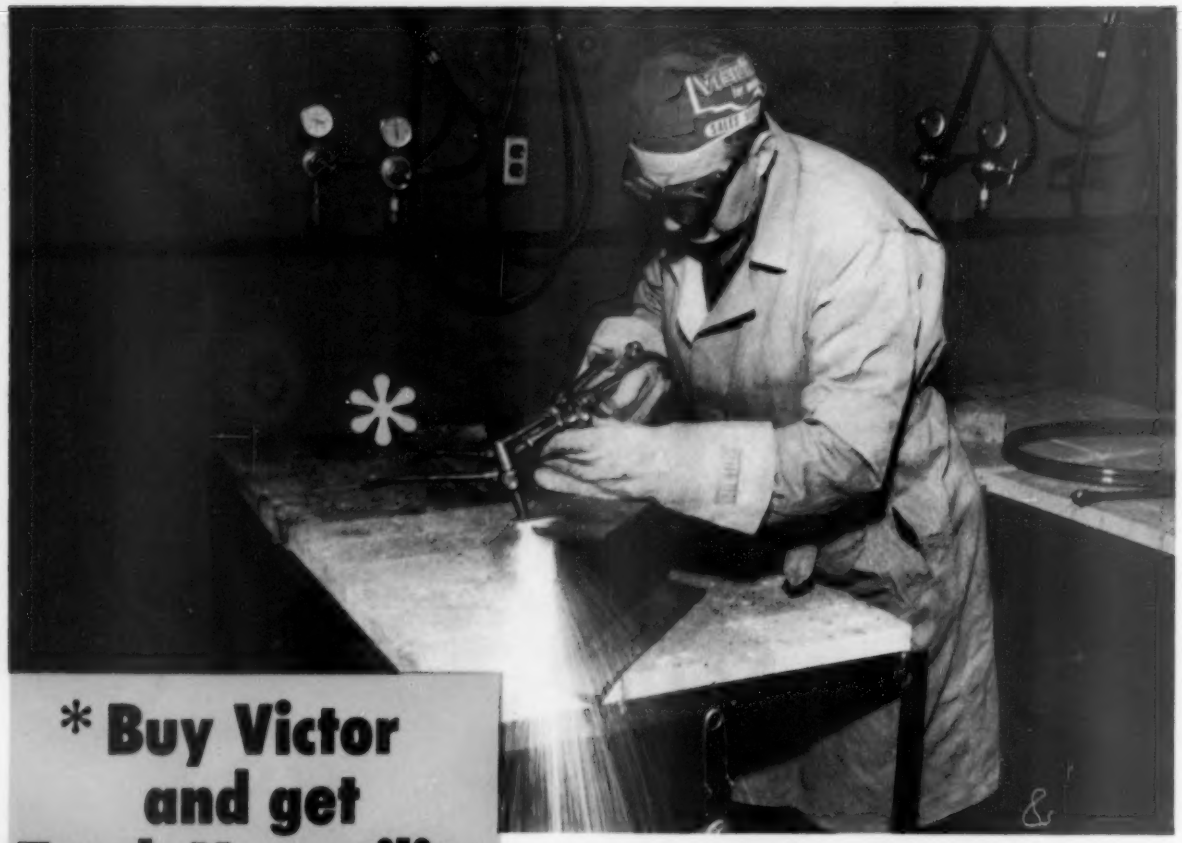

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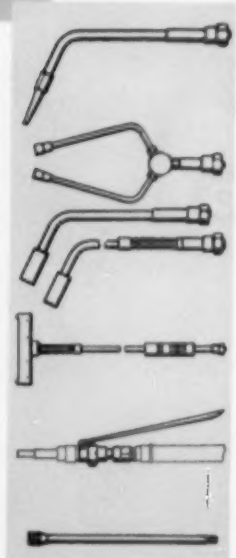

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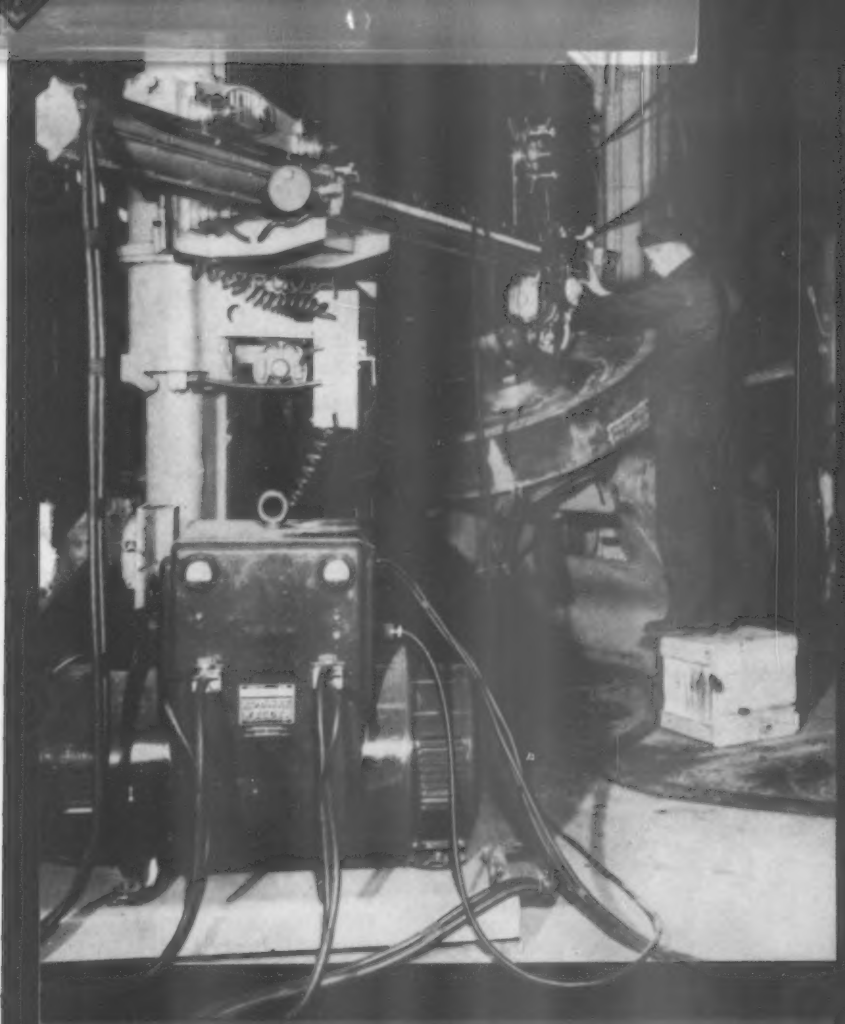

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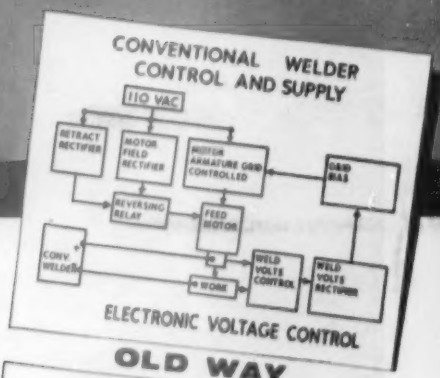

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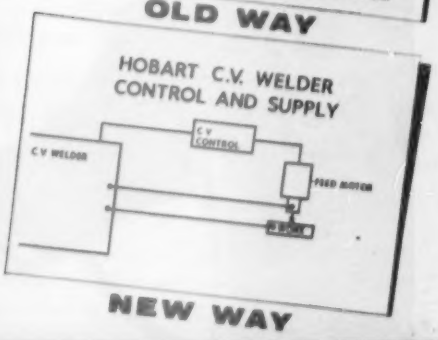

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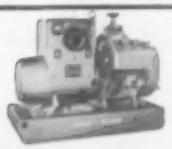

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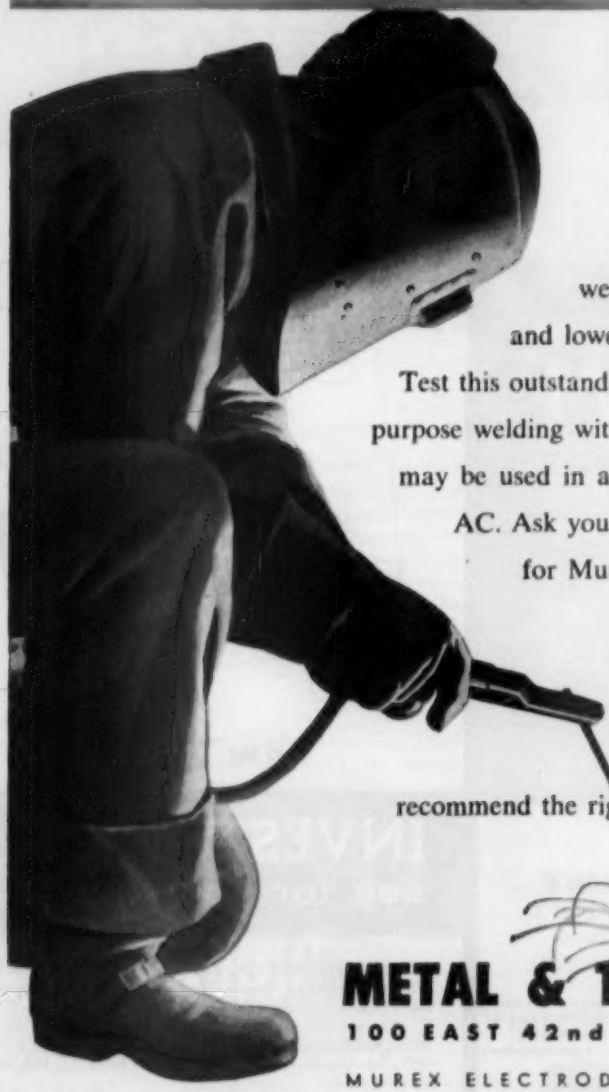

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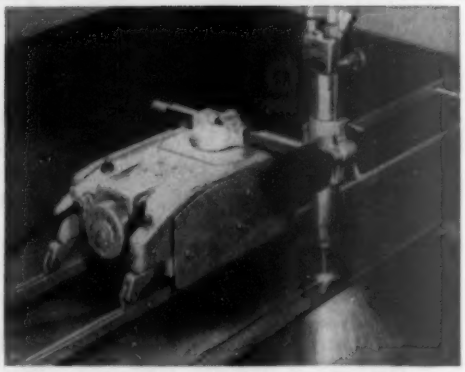

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EDITORIAL

CHOOSING OUR NATIONAL OFFICERS

The success of any Society depends, in large measure, upon the caliber of its National Officers. The members of the AMERICAN WELDING SOCIETY have been exceptionally fortunate in that their leaders, during the past 36 years, have exhibited unusual interest, ability and devotion in directing its varied activities. The continuing growth of our SOCIETY and the expansion of its activities make it increasingly necessary for these officers to devote a large portion of their time, and much effort, to the duties of their respective offices. They must be representative of the SOCIETY in every way—those whom they will contact will measure the SOCIETY by their appraisal of its standard bearers. This is particularly true with regard to the President.

The President, as First Officer of the SOCIETY and Chairman of its Board of Directors, must have unusual leadership characteristics and supervisory experience. He must be able to organize activities, allocate duties and delegate responsibilities to others. He should have a broad background and experience in Section, District and National Society activities. He should have a comprehensive knowledge of the welding, manufacturing and user industries. He will preside at public, board and committee meetings and must, therefore, have poise, be able to speak extemporaneously, hold the attention of an audience, and have a fair knowledge of parliamentary procedure. He will need imagination, courage and lots of energy.

In addition, the SOCIETY President must be associated with an organization which will allow him to invest time and funds, and which will provide him with all necessary facilities for conducting the activities required to fulfill the duties of his office, not only during his term as President but also as a member of the Board of Directors for several years.

The AWS National Nominating Committee must soon submit nominations for National Officers for the next fiscal year. This is a great responsibility. The Committee will welcome and carefully consider all suggestions and recommendations submitted by members of the SOCIETY.

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Interesting field application of automatic hard facing. This is a portable arrangement, mounted on a skid for mobility to build up worn drill pipe joints in the southwest oil country

AUTOMATIC HARD FACING WITH MILD STEEL ELECTRODES AND AGGLOMERATED ALLOY FLUXES

Author discusses the mechanics of the process of hard facing using a mild steel electrode and an alloy flux, the equipment required and how it operates. The economies of the process and a few general procedure suggestions are also given

By J. S. McKEIGHAN

Field experience during the past year has proved that automatic hard facing with mild steel electrodes and agglomerated fluxes both reduces the direct cost of hard facing and also increases the service life of machine parts.

This relatively new method of creating a wear-resistant weld deposit employs standard automatic welding equipment for the hidden or submerged-arc welding process but uses special hard-facing alloy fluxes. Several equipment adaptations can be made if desired to further reduce costs, but the heart of the method is the special agglomerated alloy flux.

Agglomeration is the process of mixing properly formulated, finely ground particles of fluxing materials together with a proper binder and drying the resultant agglomerate. The agglomerate is then ground to the desired size for submerged-arc welding. Each particle

J. S. McKeighan is District Engineer, Milwaukee, Lincoln Electric Co.
Presented at the Thirty-Fifty National Fall Meeting, AWS, held in Chicago, Nov. 1–5, 1954.

or grain of this agglomerated flux contains hundreds of finely ground particles tightly held together with the agglomerating agent or binder, eliminating any tendency for the alloy material to settle out or to segregate. Each grain of flux contains the preprocessed minerals and deoxidizers in their proper proportion. Therefore, each grain is chemically like every other grain, and they all have the same density. Some advantages of automatic surfacing with agglomerated fluxes are:

(*a*) They produce a very smooth, uniform, porosity-free surface which achieves more wear for a given alloy content in the weld deposit than is possible to obtain from hand-operated electrodes.

(*b*) This results in the permissible use of a lower alloy content deposit which is tough and crack free. Spalling, which frequently occurs when the part is surfaced many times with high-alloy materials, is avoided by reducing the excessive alloy content in the deposit.

(*c*) In general, it is cheaper to use a mild steel electrode and to introduce the alloys via the flux. This has the additional advantage of providing the proper alloy addition to meet the job requirements.

The Metallurgy of Hard Facing

A brief review of some of the basic metallurgy involved in hard facing will be a helpful introduction to a discussion of procedures.

The abrasion resistance of a hard-facing deposit is dependent upon two variables, namely the deposit analysis and the rate at which the deposit cools. The effect of the carbon and alloy content of a deposit on its wear resistance varies considerably depending on the rate of cooling.

The manner in which carbon occurs in a particular deposit, and therefore its hardness, depends upon the cooling rate. Alloys, on the other hand, control the manner in which carbon occurs in a deposit at any given cooling rate.

(*a*) If the carbon is in solution with iron, the structure is called austenite. Austenite is characterized by being nonmagnetic, soft, tough and having good abrasion resistance.

(*b*) If the carbon is not in solution with iron, the structure is called martensite. Martensite is characterized by being magnetic possessing high hardness and good abrasion resistance.

(*c*) If the carbon is dispersed—partly in solution and partly out of solution—the structure is termed to be intermediate. Intermediate structures, depending on their cooling rates, may exhibit the following properties: hard with good abrasion resistance; hard with poor abrasion resistance; and soft with poor abrasion resistance.

ITEM	FLUX	ELEC.	ARC VOLTS	% CARBON DEPOSIT	COOLING RATE	HARDNESS	ABRASION RESIST. GRAM LOSS
1	MILD STEEL (840)	.12 C (L-60)	28-32	.08	SLOW FAST	61 RB 86 RB	40 33
2	MILD STEEL (840)	.55 C (L-201)	28-32	.35	SLOW FAST	70 RB 30-33 RC	38 23
3	MEDIUM HIGH ALLOY (H-350)	.55 C (L-201)	32	.95	SLOW FAST	24 RC 42-54 RC	24 3.5

Fig. 1 Test results to show the effect of deposit analysis and cooling rate on wear resistance

The chart, Fig. 1, presents test results to illustrate the effect of deposit analysis and cooling rate on wear resistance of weld deposits. Test samples were made with automatic submerged-arc welding using agglomerated fluxes.

In mild steel welding, the weld deposit is of such low carbon and alloy content that even under the rapid rates of cooling encountered in welding, the deposit will not harden appreciably. Consider Item 1 in Fig. 1. The flux (840) with which the sample was made was a mild steel welding flux, and the alloy addition into the deposit was negligible. The electrode (L60) was mild steel with a carbon content of 0.07 to 0.14%. The number appearing under Abrasion Resistance Gram Loss is the weight of metal expressed in grams, removed by a standard grind test during a fixed time interval. This test was established to simulate abrasive wear and to measure the abrasion resistance of the deposit. (The less grams removed, the better the abrasion resistance.) Forty grams of metal were removed when the deposit was cooled slowly while 33 g were lost upon rapid cooling. Next, consider Item 2 of the same chart. The same flux and welding procedure were used, the only difference being that L201 electrode containing 0.54 to 0.65% carbon was used instead of L60 electrode. Now, upon slow cooling 38 g of metal were removed, and rapid cooling resulted in a removal of only 23 g.

The fast cooling rates used to form the desired deposit structures for best abrasion resistance represent that cooling rate which occurs when a bead is deposited on a piece of mild steel, $1^1/_4$ x $1^1/_4$ x 10 in., with an automatic welder at 400 amp, 28–32 arc volts at a rate of 28–30 ipm travel and allowed to air cool to 200° F between passes. For the slow cooling rate the welding procedure was identical to the fast-cooled samples, but in order to insure the formation of the desired slowly cooled structures, the samples were reheated to 1600° F and furnace cooled.

It now becomes apparent that by increasing the carbon content of the deposit (in this case from 0.08 to 0.35%) and by rapid cooling the abrasion resistance of mild steel can be almost doubled.

From the foregoing, it would appear that to increase the abrasion resistance of a hard-facing deposit, all that would be required is to increase the carbon content of the deposit and to cool the deposit rapidly after welding. This approach is not entirely satisfactory. If the carbon content is raised much further, the impact resistance of the deposit will be very poor. In order to obtain a deposit with good abrasion resistance, consistent with the required impact strength, to prevent spalling, the carbon *plus alloy* approach is better than merely using high carbon and rapid cooling rates.

To understand the carbon plus alloy principle, consider Item 3 of Fig. 1. The deposit in this example was

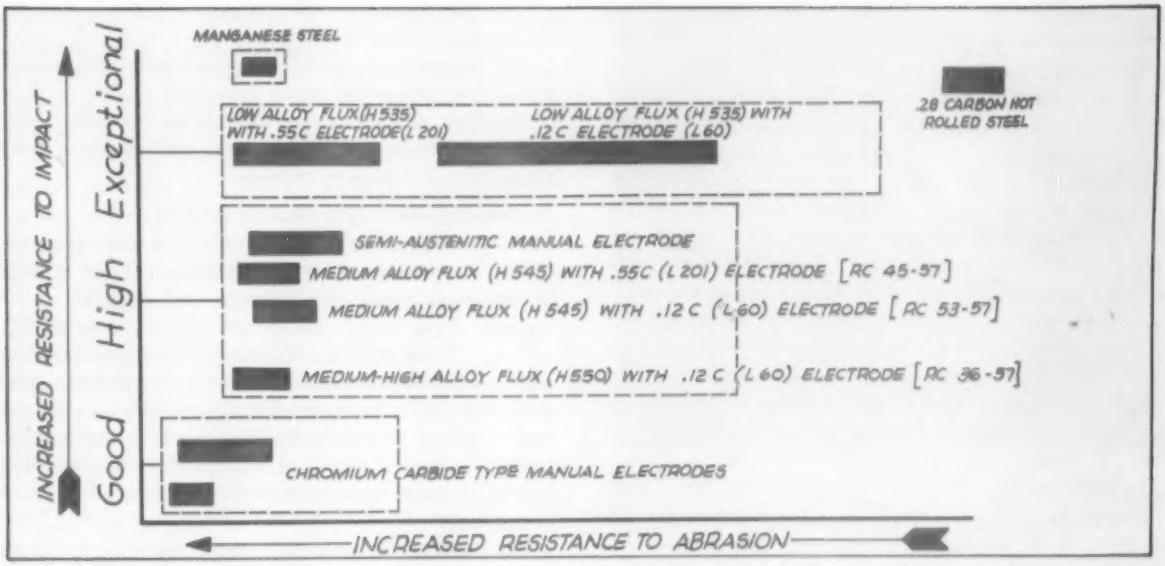
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Fig. 2 Hard facing agglomerated fluxes and their relative properties

made with L201 electrode (0.54 to 0.65% carbon) and with H550 hard-facing flux. This produces a deposit which, in addition to carbon, contains manganese, silicon, chromium and molybdenum. The characteristics of this deposit, Item 3, are compared with Items 1 and 2. The gram loss difference between a mild steel deposit (Item 1) and a hard-facing deposit (Item 3) is less than two to one when both were cooled slowly, but the difference is ten to one when both were cooled rapidly. The slow cooling rate was the same for all cases as was the fast cooling rate. From this it can be seen that the abrasion resistance of a hard-facing deposit is dependent on both the deposit analysis and the way in which the deposit is cooled.

The Importance of Cooling Rates

In the foregoing discussion we have attempted to establish the following concepts:

(*a*) In mild steel welding the deposit is of such low carbon and alloy content as to remain relatively unaffected by various cooling rates (Item 1).

(*b*) By slightly increasing the carbon content (Item 2) a rapid cooling rate produces better abrasion resistance.

(*c*) By increasing the carbon content somewhat further and by adding alloys to the deposit, a rapid cooling rate produces a marked increase in abrasion resistance of the deposit (Item 3).

The next point to establish is this: as the carbon and alloy content of the deposit are increased, rapid cooling rates become less necessary. A very substantial increase in the carbon plus alloy content results in a "carbide type" deposit (4.0 to 5.0% carbon) which is practically unaffected by cooling rates. This type of deposit has, as far as we know today, the best abrasion resistance attainable, but it has rather low resistance to impact and is apt to crack easily.

Hard Facing with Agglomerated Hard-FacingFluxes

There are three types of agglomerated hard-facing fluxes available. The relative properties of these electrodes are shown in Fig. 2.

When using these fluxes and mild steel electrodes the deposit hardness will increase and, consequently, the ease of machinability will decrease as:

1. The carbon and alloy content of the deposit is increased. This occurs as:

(*a*) The welding current is decreased.
(*b*) The arc voltage is increased.
(*c*) The carbon or alloying content of base metal is increased.
(*d*) The electrode size is increased.
(*e*) Welding speed is decreased.
(*f*) The bead overlap is increased.
(*g*) The number of layers is increased (up to and including three layers).

2. Cooling rate is increased. This occurs as:

(*a*) The ambient temperature is decreased.
(*b*) Preheat or the interbead temperature is decreased.
(*c*) The welding current is decreased.
(*d*) Welding speed is increased.
(*e*) The mass (section thickness) is increased.

Low-Alloy Type Hard-Facing Flux

This flux produces a machinable deposit of fair to good abrasion resistance and excellent impact resistance. The deposit, depending on the procedure, can be machined either with carbide or high-speed tools. It will produce a dense deposit less sensitive to cracking than a high carbon deposit of the same abrasion resistance. A two-layer deposit made with this flux and

0.12 C mild steel electrode will have 1.5–2.5 times the abrasion resistance of a machinable hot-rolled medium-carbon steel and up to twice the abrasion resistance of a deposit made with SAE 6150 wire and mild steel flux.

This flux with mild steel wire is ideal for both *build-up* and *hard facing*. Different deposits can be obtained by varying the arc voltage. Machinable deposits or built-up deposits, as required on tractor rollers and idlers, are easily obtainable at the low voltage setting (28 v). After the work is built up to within two layers of gage, a hard-facing deposit of required abrasion resistance and hardness can be made simply by increasing the arc voltage to 32 v. Thus it is possible to build up and hard face without flux or wire change. The deposit is magnetic at room temperature and has a consistent hardness. (Always allow the deposit to cool to room temperature before checking hardness.) The hardness, depending on the procedure, will range between 33 and 57 Rockwell C. This martensitic-type deposit is a low-carbon alloy steel which may be annealed or which may be quenched from above the critical temperature to harden.

The weld metal is an alloy of carbon, manganese, silicon, chromium, molybdenum and vanadium.

This flux and mild steel wire should be used wherever a smooth, dense, crack-free, machinable deposit is required such as on steel mill roll necks, blooming mill spindles, skelp rolls, pipe straightening rolls, kiln rollers, crane wheels, caterpillar rollers, idlers, and extruder rams.

Medium-Alloy Type Hard-Facing Flux

This deposit made with mild steel wire is recommended wherever smoothness and minimum porosity are the essential requirements. A minimum of two layers is recommended for good abrasion resistance. It is a good selection for applications wherever metal-to-metal wear exists. Often the economics of manufacturing will sacrifice some abrasion resistance for single layer, easily forgeable deposits as required on plow share blanks, plow shims, etc

The deposit is magnetic at room temperature, and with recommended procedures has a consistent hardness of 48–57 Rockwell C. The deposit is heat treatable by following normal heat-treating practices. Always allow the deposit to cool to room temperature before checking hardness or putting into service.

The impact strength may be increased by reheating or "drawing" a multilayer deposit from room temperature to some predetermined temperature up to 1050° F and holding at that temperature 1 hr for each inch of thickness without sacrificing hardness or abrasion resistance at room temperature.

For all practical purposes, the hardness, the abrasion resistance and the deposit analysis change only very slightly after the third layer.

The weld metal is an alloy of carbon, manganese, silicon, chromium, molybdenum and vanadium.

This flux and (0.12 C) mild steel electrode are especially recommended for the following applications:

(*a*) For deposits to be forged such as plow share blanks, plow shims, etc.

(*b*) For metal-to-metal wear, such as tractor rollers, idlers, crane wheels, extruder rams, etc.

(*c*) For smooth deposits without porosity and underbead cracking, such as steel mill roughing rolls which do not require machining.

Medium-High-Alloy Type Hard-Facing Flux

The deposit made with (0.12 C) mild steel electrode should be used wherever a single-layer deposit of high abrasion resistance and good impact strength is required. Base metal should not contain over 0.60% carbon. This flux is recommended for fabricated parts such as scraper blades, parts of mixers, etc. The deposit is also recommended for multiple-layer deposits requiring high abrasion resistance such as required on crusher rolls, crusher bowls, mantels, etc., whether originally made from carbon steels, manganese steels or cast iron.

The deposit is magnetic, semiaustenitic at room temperature and has, with recommended procedures, a consistent hardness. A broad range of 36 to 62 Rockwell C can be developed by controlling the weld metal analysis and the cooling rate. Always allow the deposit to cool to room temperature before checking hardness or abrasion resistance. The deposit is dense and forgeable. It is nonmachinable and can be finished to size only by grinding. The deposit is heat treatable by following normal heat treating practices.

As with medium alloy flux, the impact strength may be increased by reheating or "drawing" the multilayer deposit form room temperature to some predetermined temperature up to 1050° F and holding at that temperature 1 hr for each inch of thickness without sacrificing hardness or abrasion resistance at room temperature. The hardness, the abrasion resistance and the deposit analysis change only very slightly after the third layer.

The deposit is an alloy of carbon, manganese, silicon, chromium and molybdenum.

This flux and mild steel electrode are specially recommended for the following applications where extremely abrasion-resistant deposits are required: scraper blades, crusher rolls, mantels, large shaker screens, mixer liners, crusher bowls, extruder piston heads, and lifting magnets.

Accessory Equipment for Automatic Hard Facing

Recent developments in accessory equipment for automatic heads are uniquely advantageous for automatic hard facing. Two of these accessories are fully developed and are available on the market today. Both were developed almost coincidentally, and it is difficult to evaluate which is of greatest importance. In many cases, they are both used simultaneously in the same installation and so far produce better results than either one individually. These items are the oscillator and the multiple arc adaptations for a standard automatic head.

The oscillating or arc-spreading device is an

attachment which provides a means of producing a surfacing layer of metal up to over 3 in. wide with one pass. An installation showing this attachment in use surfacing worm track pads from a crawler crane is shown in Fig. 3.

The multiple arc adaptation, as will be observed herein, is simply an attachment for a submerged-arc automatic head which permits the simultaneous feeding of two electrodes through one head. This is shown in Fig. 4. This reduces the cost of surfacing because with two wires, the rate of deposition of weld deposit can be substantially increased over that of a single electrode without increasing the penetration. Penetration is normally undesirable in hard facing because the base metal dilutes the alloy deposit. For surfacing, the two wires are normally placed side by side. The two wires are fed through the same head at the same speed and are supplied from a common source of power. This photograph shows both attachments mounted on the same head and depositing hard-facing layers over 3 in. wide in one pass.

In addition to showing the application of these accessories, this picture also shows the first step in surfacing a mixer bottom liner which originally was made of 12% manganese steel. Figure 5 shows the completed mixer bottom liner.

Because of the difficulty of obtaining this $^{3}/_{8}$-in. thick material and getting it cut to the required size of 53 by 58 in. and then welding it into a watertight bottom, the 12% manganese steel plates were replaced by SAE 1015 plates which were hard faced by hand. The resultant surfaced plate lasted twice as long as the 12% manganese liners.

The hard facing of these liners has now been converted to submerged arc using the agglomerated alloy flux, mild steel electrode, adaptations to the automatic head. The surfaced area is 51 in. long by 43 in. wide

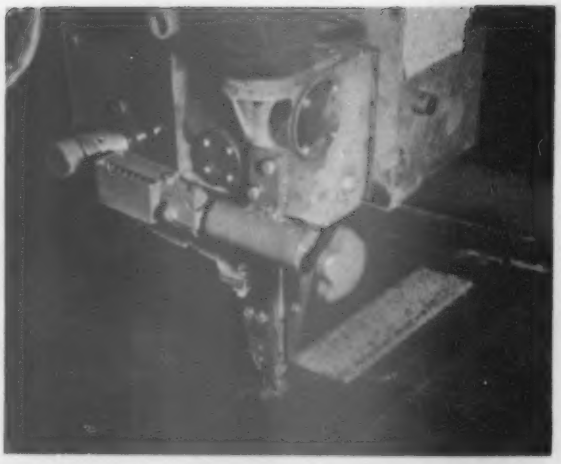


Fig. 4 Here the automatic head has been adapted for both oscillation and multiple arc operation. Two small wires are fed through the head in place of one larger wire creating two arcs and increasing deposition rate

Fig. 5 This liner for a mixer bottom has been surfaced using an automatic head, agglomerated fluxes and both multiple arc and oscillating attachments

Fig. 3 For hard facing track pads, this automatic welding head has been adapted for oscillation by the addition of suitable attachment. Beads up to 3 in. wide can be made in a single pass

bucket bits on a well-known make of tractor front-end

Fig. 6 Hard facing a round surface such as this extruder ram employs single wire and no oscillation

for each plate, or twice this amount for the whole mixer bottom.

The cost comparison between the three plates is as follows:

12% manganese steel liner (not including welding in place)	$187.75
Hand-surfaced liner	288.25
Automatic-surfaced liner	108.39

As can be seen, the hand-surfaced liner cost 50 to 60% more than the manganese steel plate. However, it was actually cheaper because it lasted twice as long. The automatically surfaced liner costs only 50 to 60% as much as the manganese steel liner and lasts more than twice as long. Therefore, the automatically surfaced plate will cost less than 30% as much as either the manganese steel liner or hand-surfaced liner.

The cost figures include the cost of the plate, the hard-facing material and labor, and overhead cost of depositing it.

On roundabout seams in the smaller diameters at least, just a single electrode and no oscillation is used. In this application, it is necessary to keep the molten puddle small so that it sets up before it gets a chance to run off. Figure 6 shows an extruder ram being surfaced as a typical example. This extruder ram, 7 in. in diameter 142 in. long, was built up $^1/_4$ in. on the diameter for a length of 128 in. The gouged and scored ram was undercut $^1/_8$ in. on the diameter and then preheated to 150–200° F at the beginning of welding. Using $^1/_8$-in. mild-steel electrode and the medium

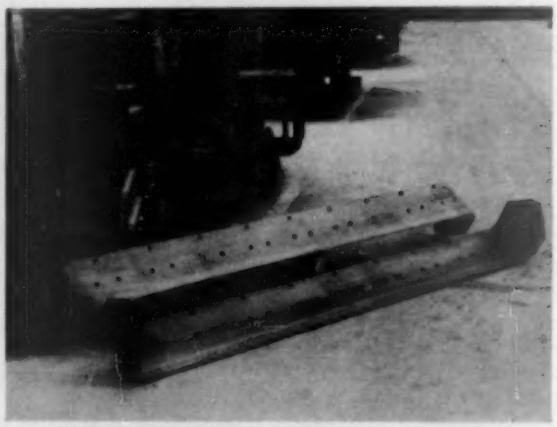


Fig. 7 Hard facing is used as a production process in making these bucket bits for a tractor front end loader

Fig. 8 Setup for making bucket bits. The bit is bolted to a large angle to control distortion. An oscillating head is used

alloy hard-facing flux, 125 lb of metal were deposited on the ram in a total time of 10 hr, 30 min. With labor and overhead figured at $5.00 per hour, the total cost of this job, including 32 hr of grinding, was $268.98. A new ram costs $898.85, thus saving $629.87.

Another application which has proved very successful as a production process is the automatic surfacing of bucket bits on a well-known make of tractor front-end loader. These bits are 96 in. long and are surfaced on each side of the cutting edge with a build up 2 in. wide by $^1/_8$ in. thick for the full width of the blade. The automatic hard facing is applied with medium high-alloy agglomerated flux and $^5/_{32}$ in (0.12 carbon) mild steel electrode. The travel speed is $6^1/_4$ ipm and one

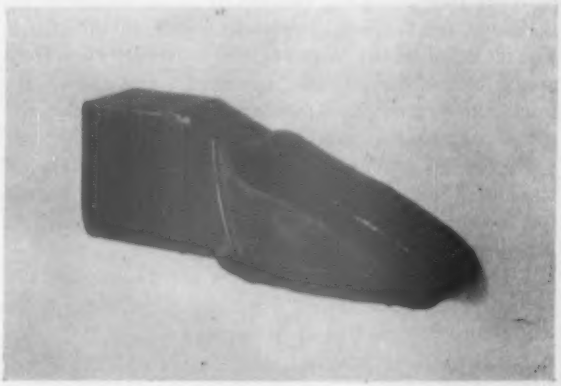
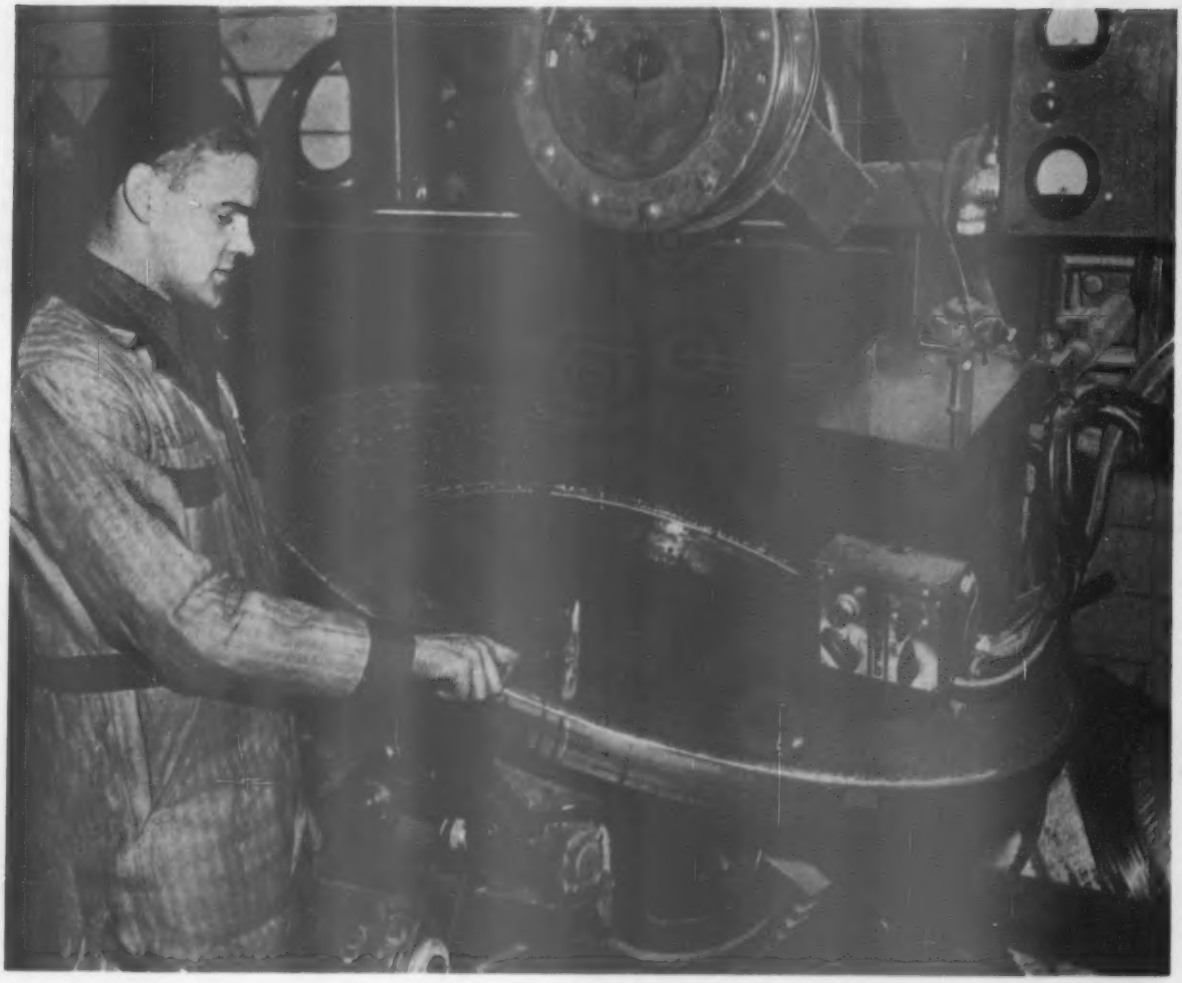


Fig. 9 A section of the bucket bit

Fig. 10 Hard facing of crusher ring from a Raymond Bowl mill used for pulverizing coal



man now produces 7 blades per day. Formerly, with manual open-arc hard facing, 2¼ blades per day was one man's output. Figure 7 shows the finished surfaced blades done automatically. The cost was formerly $25 per bit. With this automatic procedure the cost is now $10 each.

Figure 8 shows the automatic welding set up to perform this surfacing operation. The oscillator attachment for the head is clearly shown in the photo. The bit is bolted to a large angle to resist distortion from application of the surfacing material. The angle helps retain the flux and hard facing at the extreme tip of the bit during actual deposition.

Figure 9 shows a section cut from the tip of one of these blades showing the hard-facing material overlaying the cutting edge of the bit and the overlap of both layers at the extreme tip.

Additional typical applications for automatic hard facing with agglomerated fluxes are illustrated in the lead photograph and in Figs. 10 and 11.

Summary

From a deposit composition standpoint this process is, at present, commercially applicable for depositing machinable ferritic deposits and nonmachinable but forgeable semiaustenitic deposits. It is not as yet available for high tungsten and chromium carbide deposits or the austenitic manganese deposits. However, in many cases abrasion resistance can be obtained with the forgeable semiaustenitic submerged-arc deposits which are comparable to or better than those obtained with hand electrodes that are supposed to produce nonforgeable chromium carbide deposits. In theory, this should not be so. Practically it is because the submerged-arc deposit produces a chemically more uniform and a physically smoother deposit than is frequently achieved with the chromium carbide hand deposit. Therefore, there are no weak points at which the wear starts.

From a shape standpoint, submerged-arc surfacing is usable for flat and roundabout deposits. On roundabout deposits, it is being applied on parts as small as 4 in. in diameter. On flat surfaces, it is being applied on parts requiring a surfaced length as short as 3 in.

For a general cost comparison, the submerged-arc automatic in conjunction with the agglomerated alloy flux, oscillator and multiple arc units, will surface at a cost of approximately 20 cents per cubic inch of deposit and the hand electrode approximately one dollar for the same wear resistance. Wear resistance is frequently sacrificed in hand welding, and the cost may drop to 50 cents per cubic inch of deposit. This cost is for the forgeable but nonmachinable, semiaustenitic deposit which is the most commonly used deposit in both automatic and manual hard facing. In each instance, this cost is based on 50% arc time and a labor and overhead cost of $5 per hour. In specific applications, of course, the difference between hand and submerged arc may be greater or less than the above figure.

The capital investment, in order to surface by automatic or semiautomatic welding, will vary greatly depending largely on the fixturing required. Cost figures however, can readily be determined, and with these figures it becomes a matter of arithmetic as to whether it is more economical to surface by hand or submerged arc. The number of cubic inches to be surfaced per year multiplied by the difference between the cost by welding hand and submerged arc represents the potential saving per year. If this saving will justify the difference in capital equipment between submerged arc and hand welding, hardfacing should be done by submerged arc.

Acknowledgment

The author desires to express his appreciation for the contributions of L. K. Stringham, V. Peters, R. A. Wilson, Kurt Rose and C. G. Herbruck of the Lincoln Electric Co. in the preparation of this paper.

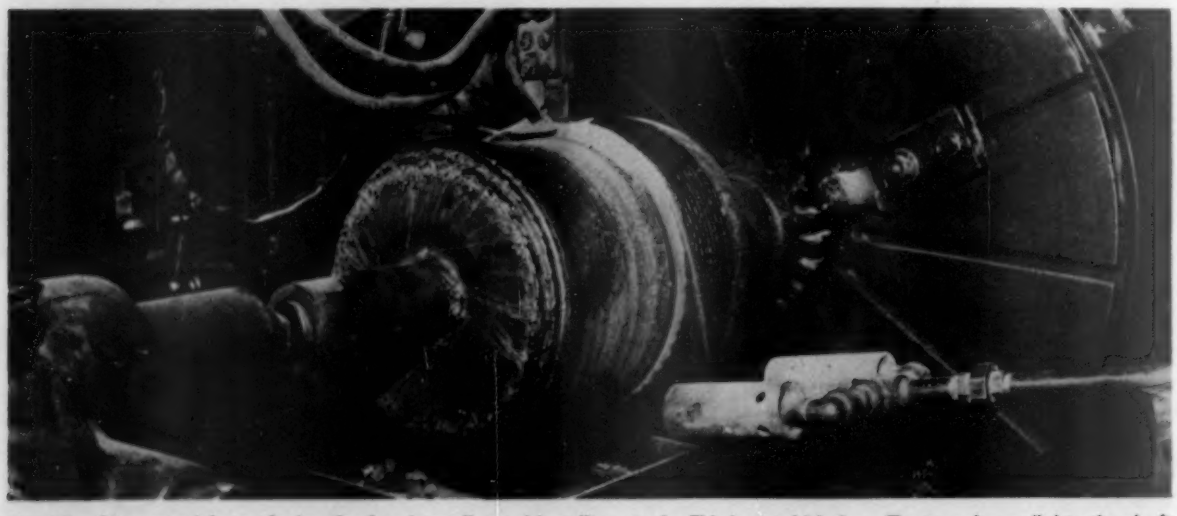


Fig. 11 Setup used for surfacing the forming rolls used in rolling steel. This is an old lathe. The travel parallel to the shaft is obtained with the lead screw.

INERT-GAS METAL-ARC CUTTING

New consumable electrode inert-gas metal-arc cutting process effectively produces straight-line, circular and shape cuts on nonferrous metals

BY R. S. BABCOCK

A new process has been devised for cutting nonferrous metals which normally resist oxidation in the standard oxygen-cutting process. This should prove to be a boon to the metal fabricating field in shaping sections of nonferrous plates preparatory to welding. Clean, bright metal surfaces are produced at extremely high cutting speeds on aluminum and other nonferrous metals and alloys. This new process is a metal-arc-cutting operation in which a consumable electrode is used and the arc and active zone are shielded with an inert gas. In this paper, it is referred to as inert-gas metal-arc cutting. This process uses inert-gas metal-arc welding apparatus with a few minor changes to take care of the increased power, wire feed rates and different shielding gases demanded by the process for its successful operation.

Process Description

An inert-gas metal-arc cutting setup includes the items shown schematically in the diagram on Fig. 1. Any standard inert-gas metal-arc welding torch can be used for the type of cutting in question but the size of the torch that should be used depends upon the thickness of metal to be cut, power capacity and size of the consumable electrode. The consumable electrode is generally a steel wire of suitable size; $^{5}/_{32}$-in. diam steel wire has been used extensively in tests made to date by the author. The wire-feeding apparatus includes electronic controls, wire reel and wire driving unit with suitable gearing to meet wire consumption rates required by the workpiece thickness and wire size. Water cooling of the torch is needed to protect the apparatus at the high currents employed. In some apparatus, water-cooling permits the use of smaller and more flexible power cables between the control unit and torch. A suitable source of d-c power is required. The capacity which is necessary depends upon the thickness and type of metal being cut.

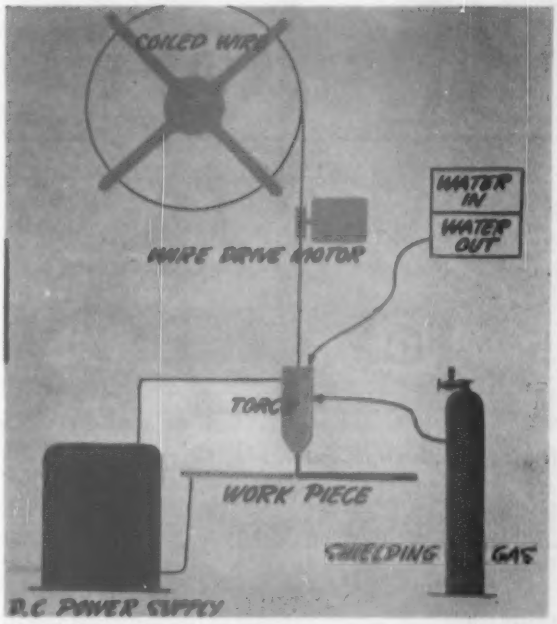


Fig. 1 Schematic diagram of a basic inert-gas metal-arc cutting setup

Although inert-gas metal-arc cuts can be made with both manual or mechanized welding torches, the lower current capacity of manual torches limits the thickness of metal which can be cut effectively by this equipment. In cutting a given thickness of metal, higher currents give faster cutting speeds than lower currents, but the wire consumption is likewise proportionally higher.

In order to more clearly illustrate this cutting process, an enlarged diagrammatic sketch of the cutting reaction is shown in Fig. 2. The torch is advanced over the workpiece along the desired line of cut at a constant rate of speed. As the torch advances and the wire is brought into contact with the workpiece, an arc is established between the wire and the workpiece. The arc energy progressively removes a controlled amount of metal to form a slot or kerf along the desired line of cut. The cutting arc differs from a welding arc in its location. A welding arc extends from the tip of the wire, a cutting arc extends from the side of the wire. The steel wire is fed through the torch at sufficient speed so that the tip of the wire reaches the bottom or underside of the workpiece. For a given power, there is a maximum cutting speed and a most effective wire-feed rate for optimum

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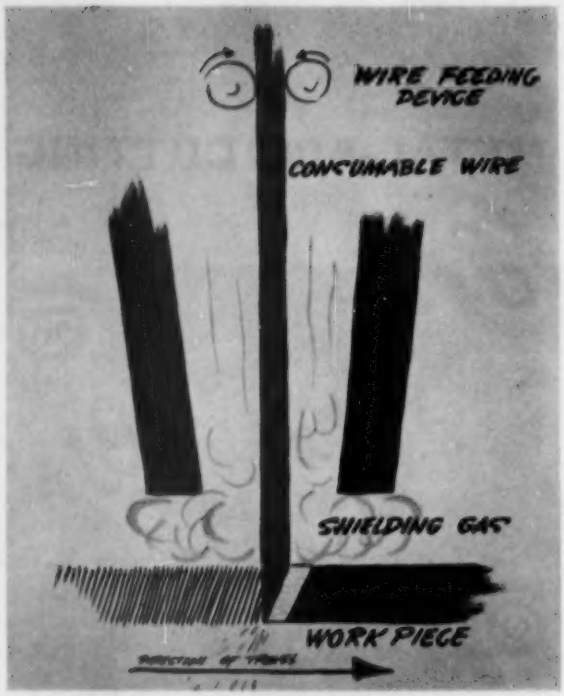

Fig. 2 Basic inert-gas metal-arc cutting reaction

quality cuts on different thicknesses and types of material.

The cutting arc with this process extends over the entire surface of the leading side of the wire from top to bottom of the workpiece. The arc consumes the wire on the leading side so that it becomes tapered in passing through the workpiece (see Fig. 2). If the tip of the wire is even with the bottom of the workpiece, the kerf or cut width will be uniform and the exhausting slag or dross will be more completely discharged. When the tip of the wire is closer to the top of the workpiece, the cut surface is top-beveled and the slag adheres to the bottom of the cut. Excessive wire feed rates produce under-beveled kerfs, and lead to lost cuts, gouges in the kerf, intermittent piercing and deposit of cold rod on the top of the base metal. It is therefore very important that wire feed and cutting speed be held constant for uniform high quality cuts.

Power for inert-gas metal-arc cutting should be obtained from a direct-current power supply of adequate capacity. Tests indicate that the range of current that can be used with standard inert-gas metal-arc apparatus is between 450 and 900 amp. This cutting process works best when reverse polarity is employed.

The shielding gas best suited for inert-gas metal-arc cutting appears to be argon. Other gases which have been tried include hydrogen, helium, oxygen, nitrogen, air and carbon dioxide. Cut surfaces obtained with these gases were not usable in the as-cut condition due to roughness, discoloration, contaminated metal, adhering slag and/or failure to cut uniformly. Argon flow rates depend on material thickness and are in the order of 20 cfh for average conditions. Slightly lower flows have been successfully employed in a few instances, but the higher flow seems to give more consistent results. Since the effectiveness of the inert-gas metal-arc cutting process is a result of arc force rather than gas velocity, there is no advantage to be anticipated from the use of higher gas flows, except as required for adequate shielding on thicker material.

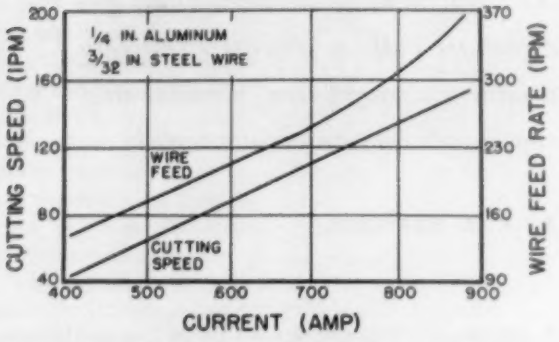

Fig. 3 Typical curves for aluminum. Relation of current to cutting speed and wire feed rate for inert-gas metal-arc cutting of 1/4-in. aluminum with argon shielding

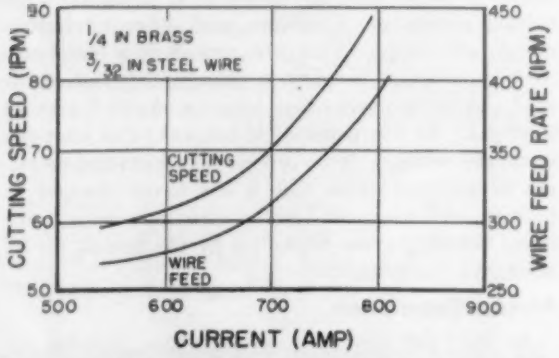

Fig. 4 Typical curves for brass. Relation of current to cutting speed and wire feed rate for inert-gas metal-arc cutting of 1/4-in. brass with argon shielding

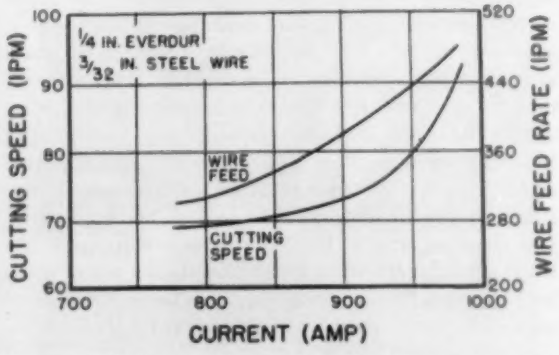

Fig. 5 Typical curves for Everdur. Relation of current to cutting speed and wire feed rate for inert-gas metal-arc cutting of 1/4-in. Everdur with argon shielding

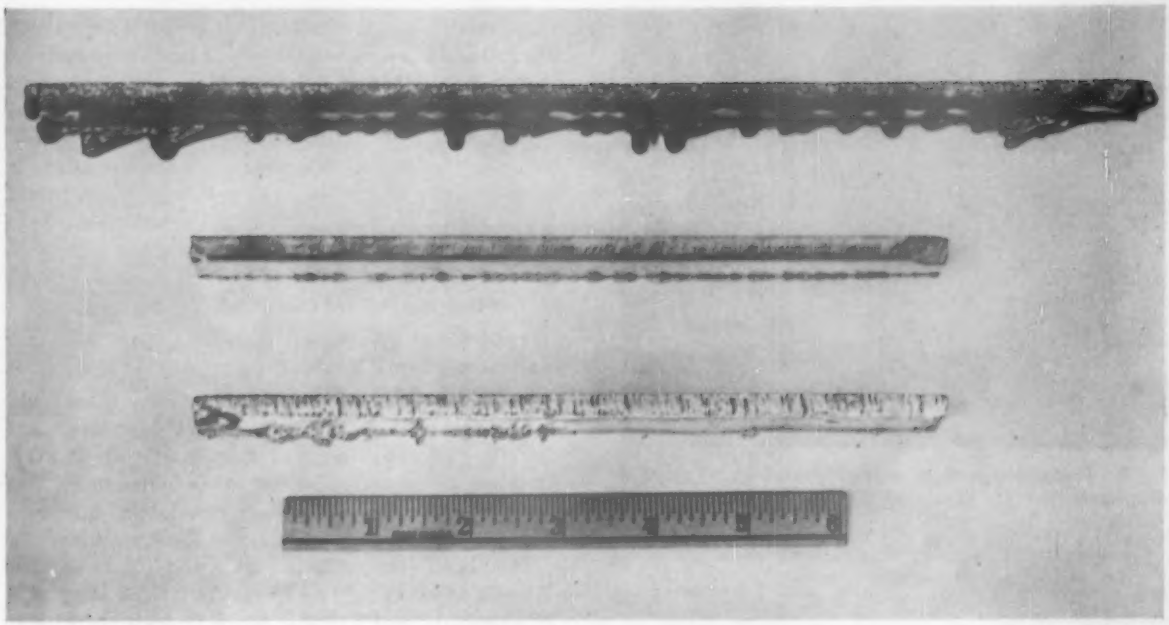

Fig. 6 Inert-gas metal-arc cuts on 1/4-in. copper, brass and aluminum with argon shielding

Test Data

Typical cutting speed versus current and wire feed rate versus current curves are shown in Figs. 3, 4 and 5 for 1/4-in. thick aluminum, brass and Everdur respectively. Representative data for various thicknesses of several metals and alloys are presented in Table 1.

Table 1—Inert-Gas Metal-Arc Cutting Data

Material	*Thickness, in.*	*Current (DCRP), amp*	*Wire feed, ipm*	*Speed, ipm*
Aluminum	1/4	410	140	47
		540	195	65–72
		620	215	90–98
		760	285	120–144
		880	370	144+
	5/16	640	290	65
	3/8	660	200	50
		800	250	75
		860	300	87
	1/2	880	560	45
Copper	1/4	880	400	60
Magnesium	1/2	640	275	85
Brass	1/4	550	270	60
		700	310	70
		800	390	90
Everdur	1/4	800	310	70
		940	425	77
		920*	375	78
		980	475	90
Nickel	1/4	800	375	37
		1000	700	57
		1000*	525	72
Inconel	1/4	1000	600	57
		1000*	525	72
Monel	1/4	1000*	525	85

NOTE: All cuts were made with 3/32-in. Oxweld No. 32CMS wire and 20 to 30 cfh argon except data marked with asterisk which used argon plus 10 to 15% oxygen. Data over 900 amp obtained with special mechanized setup, high-speed wire feed and 1000 amp capacity power source.

Typical cutting speed versus current and wire feed rate versus current curves are shown in Figs. 3, 4 and 5 for 1/4-in. thick aluminum, brass and Everdur respectively. Representative data for various thicknesses

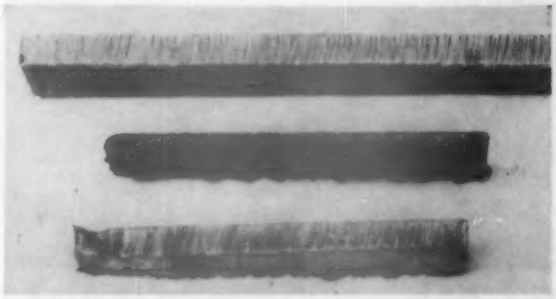

Fig. 7 Inert-gas metal-arc cut 1/2-in. aluminum, 1/4-in. copper and 1/2-in. magnesium using high currents with argon shielding

Typical inert-gas metal-arc cuts on 1/4-in. copper, brass and aluminum are shown in Fig. 6 using argon as the shielding atmosphere. These cuts were made with high currents and high wire feed rates at cutting speeds of 60, 90 and 144 ipm, respectively. The inert-gas metal-arc cutting process can be started at the edge of the material or by piercing a hole through the material at any point in the plate surface. Very little dross was ejected on to the surface of the plates during the piercing. The kerf width throughout the length of the cuts was uniform, and of the same order of magnitude as the diameter of the wire (3/32 in.).

Results obtained with 1/16-in. steel wire on 1/4-in. aluminum gave slightly higher cutting speeds with currents of 390 to 510 amp, but the performance was not consistent.

Tests Using High Amperage

Cursory tests with a d-c power supply between 1000 and 1300 amp indicate that 1/2-in. aluminum, 1/4-in.

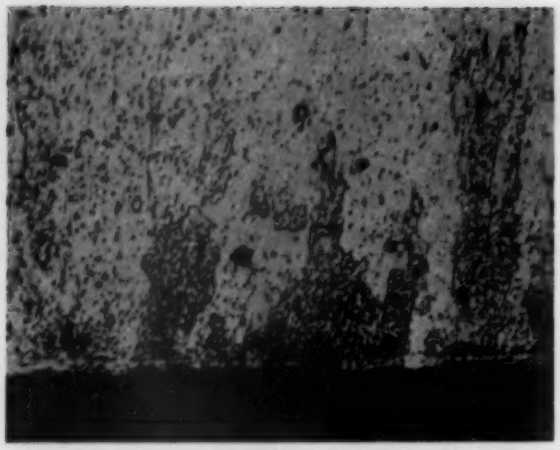

Fig. 8 Photomicrograph of inert-gas metal-arc cut edge of aluminum. X 100. (Reduced 50%)

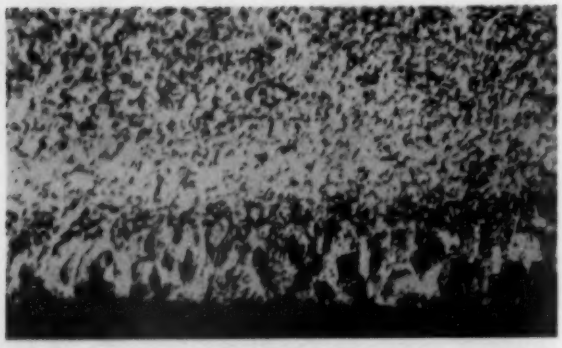

Fig. 9 Photomicrograph of inert-gas metal-arc cut edge of Everdur. X 100. (Reduced 50%)

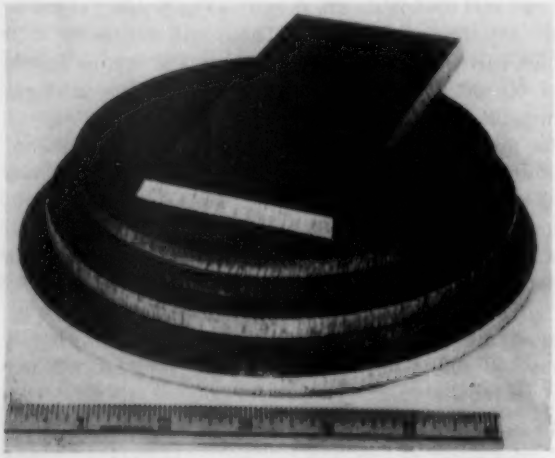

Fig. 10 Inert-gas metal-arc cut 1/4-in. aluminum, bevel and circles with argon shielding

copper and 1/2-in. magnesium can be cut at speeds of 100, 120 and 144 ipm, respectively, as shown by samples on Fig. 7. However, extremely high wire feed rates are required to maintain the desired cutting action and this together with the high currents indicates the probable need for special apparatus. Some attention is being given to the use of larger size wire which would necessitate a slower burnoff rate of the electrode. It is expected that further information on these phases of the inert-gas metal-arc cutting investigation will be forthcoming in the near future.

Metallurgical Effects of Inert-Gas Metal-Arc Cutting

Having established that this cutting process could cut nonferrous metals, the next step was to determine the effect of using the steel wire on the cut surface. At the same time an effort was made to determine how much the arc heat affects the base metal and how deep the heat-affected zone extends from the kerf surface.

The photomicrographs in Figs. 8 and 9 show sections of metal adjacent to the kerf in 1/4-in. thick samples of 2S aluminum and Everdur cut with high currents at speeds of 144 and 90 ipm, respectively. The depth of material affected by the reaction ranges from about 0.001 in. for aluminum to 0.005 in. for Everdur. Chemical analysis of the metal adjacent to the kerf showed that in the case of aluminum, the base metal iron content was 0.44% and shavings taken from the kerf surface showed only 0.50% iron. In Everdur, the base metal contained 0.10% iron and the cut edge analyzed 0.13% iron.

In order to further check the effect of inert-gas metal-arc cutting, approximately thirty weld test sample plates of 2S aluminum 1/4 by 4 by 12 in. were cut lengthwise at 144 ipm. Several butt, fillet and corner welds were made with the inert-gas metal-arc welding process on these samples produced in this manner. Chemical analysis of samples taken from the welds, base metal and welding wire showed respective iron contents of 0.36, 0.48 and 0.24%. These tests indicate that the depth of metal affected along the kerf is so shallow and the amount of iron pickup so low, that it has little or no effect on the weld deposit. The iron content of the weld is therefore dependent upon the type of filler metal added. Nonconsumable-electrode inert-gas metal-arc welds with and without 1/16-in. aluminum wire showed that the weld sections had the same iron content as the base metal. There was no noticeable difference in the arc stability or speed of the inert-gas metal-arc welding operations, with both consumable and nonconsumable electrodes, whether the welding edges were sheared or inert-gas metal-arc cut.

Inert-Gas Metal-Arc Cutting Applications

Having established that straight-line square cuts could be made with this cutting process, a few tests were made to determine how the process could be applied to other types of cutting such as bevel-cutting and shape-cutting. It was found that bevel cuts could be made on 1/4-in. aluminum using the same operating

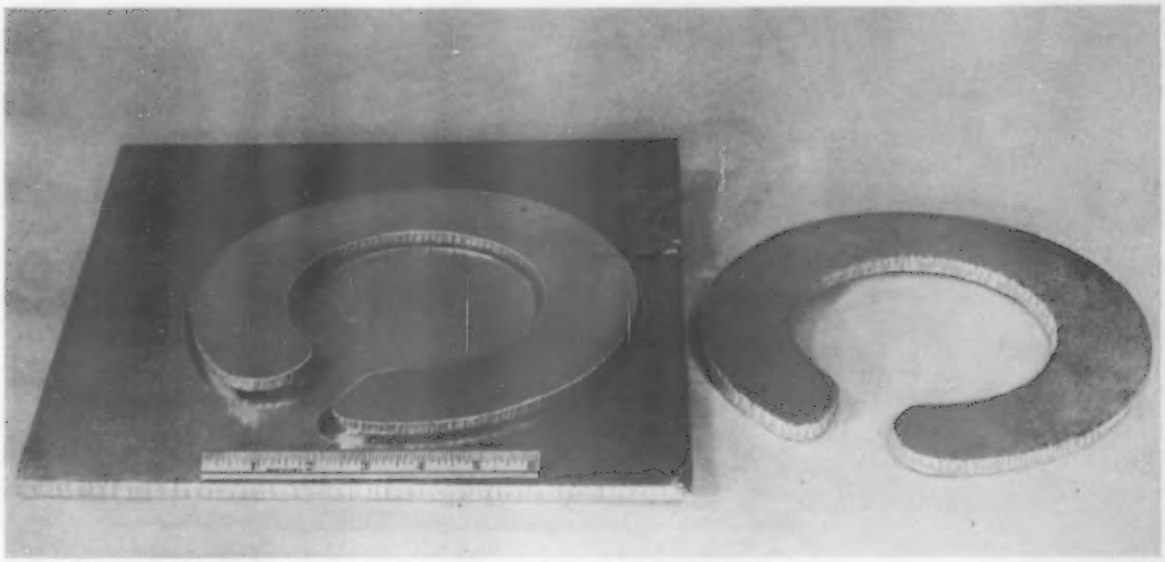

Fig. 11 Inert-gas metal-arc cut $^{5}/_{16}$-in. aluminum, shape-cut with argon shielding

conditions employed for square cutting except for a reduction in cutting speed. The decrease in speed corresponds roughly to the increased thickness of metal being cut. The cuts of kerf surfaces were equal in quality to the square cuts previously made. Circular pieces were cut from $^{1}/_{4}$-in. thick aluminum using the same conditions as used for straight-line cutting except for a slight reduction in cutting speed. The material was supported on a rotating table or positioner and rotated under a stationary inert-gas metal-arc cutting unit. Typical bevel and circular cut sections of $^{1}/_{4}$-in. aluminum are shown in Fig. 10.

In order to more thoroughly evaluate the effectiveness of the inert-gas metal-arc cutting process in shape cutting, a portable unit was mounted directly on the arm of an oxy-acetylene shape-cutting machine. On a $^{5}/_{16}$-in. thick aluminum plate, shape cuts requiring 45 linear inches of cutting were made in 42 sec using $^{3}/_{32}$-in. steel wire fed at 290 ipm and 640 amp, direct current, reverse polarity (DCRP). Several shape cuts such as those shown in Fig. 11 were reproduced consistently at this cutting speed of 65 ipm. The right-hand sample illustrates the bottom view of a circular piece cut from a plate section in the manner indicated in the left-hand sample.

A test was also made to determine whether a square-angle inside corner could be shape cut with this process. Several samples with uniform and smooth kerfs were made with three outside corners having a $^{1}/_{4}$ in. radius and an inside square corner. This $^{1}/_{4}$-in. thick aluminum plate was cut with the same conditions specified above for the $^{5}/_{16}$-in. material except that the cutting speed was increased to 70 ipm.

Shielding Gases

One of the pertinent factors in any process requiring shielding gases is the type of gas which can be used. In attempting to determine the type of gas which could be used with the inert-gas metal-arc cutting process, a series of tests was made on $^{1}/_{4}$-in. thick aluminum in which maximum cutting speeds for different shielding gases were established at a given power setting. Included in this group of tests were air, oxygen, nitrogen, helium, hydrogen, argon, (standard purity) and argon M-5 (5% oxygen). Samples cut with these shielding gases are shown in Fig. 12. The pieces, from top to bottom, illustrate cuts made with helium, air, nitrogen, oxygen, argon and M-5 argon. All cuts were made with the same apparatus, type and size of wire, and generator setting. The actual current varied depending upon the atmosphere utilized. It was noted that hydrogen failed to produce continuous severing and left a blackened kerf surface when occasional holes were pierced through the material. Consequently, there are no samples of hydrogen-cut surfaces in the group described above.

It is obvious from the samples in Fig. 12 that argon or M-5 argon produces the only acceptable quality cuts which could be used without subsequent cleaning, chipping or grinding. Nitrogen was particularly poor because the arc spattered droplets of the electrode, thereby discoloring the top surface of the metal as well as leaving a rough, discolored kerf surface.

At a somewhat later date, an effort was made to cut $^{1}/_{4}$-in. aluminum with carbon dioxide. A typical cut made with 800-amp DCRP, $^{3}/_{32}$-in. wire fed at 250 ipm, and a cutting speed of 144 ipm is shown in Fig. 13. Obviously the discoloration, kerf surface roughness and adhering slag or dross are objectionable when the cut surface is to be used in a weldment, etc., without subsequent metal removal or cleaning.

Although yellow brass could be cut rapidly and with very little adhering slag or dross using argon, tests on Everdur were less satisfactory. The test samples were

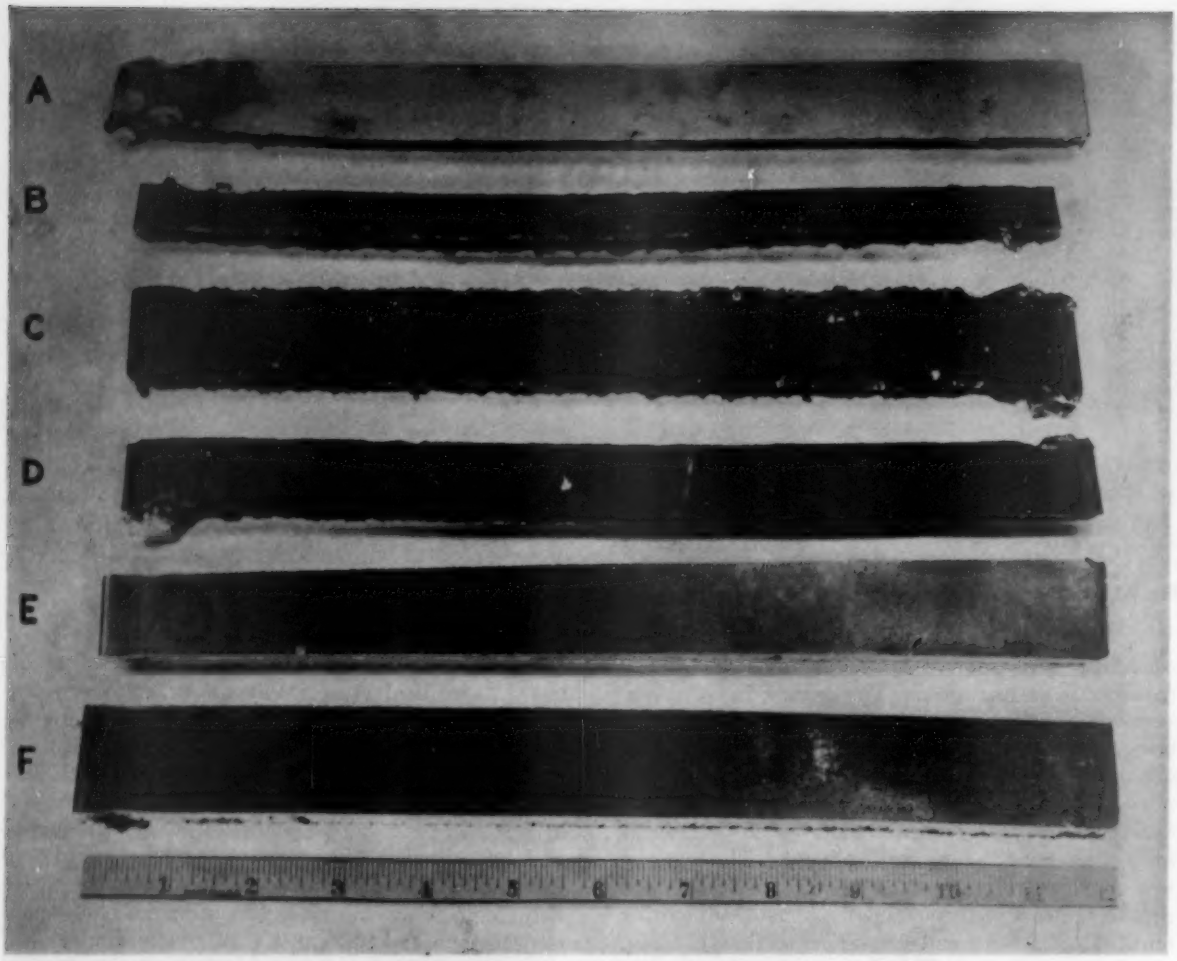

Fig. 12 Inert-gas metal-arc cut $^1/_4$-in. aluminum using the following shielding gases: *A*, helium; *B*, air; *C*, nitrogen; *D*, oxygen; *E*, argon; *F*, M5 argon

clean-cut on the base metal side, but the scrap side which was remote from the ground contact had large globules of fused metal hanging from the bottom of the kerf. The addition of 10 to 15% oxygen to the argon produced cuts entirely free of slag or dross on both sides of the kerf.

Some time later in cutting nickel, Monel, and Inconel, the same trend was noticed. Samples of these materials, $^1/_4$ in. thick by 4 in. wide, were successfully severed by the inert-gas metal-arc cutting process, but in all cases globules of fused metal were firmly attached to the bottom edge of both sides of the kerf or at least on the scrap side. By adding 10 to 15% oxygen to the argon, this condition was completely eliminated.

Manual Operation

The cutting capacity of different sizes of manual and mechanized inert-gas metal-arc welding equipment is determined by the maximum wire size and power that can be handled by the individual setup. Because manual apparatus is light and limited to smaller wire sizes and currents, the maximum thickness of metal which can be cut with such apparatus is generally less than that for mechanized apparatus. In some ways, this is a fortunate condition because it would be extremely difficult for a hand operator to cut at 144 in. or 12 fpm.

Using a hand torch, cuts have been made through $^1/_4$, $^5/_{16}$, $^3/_8$ and $^1/_2$-in. thick aluminum; $^1/_4$-in. and $^3/_8$-in. Everdur and bronze. In all cases, $^3/_{32}$-in. steel wire was employed with suitable shielding gases and currents as indicated previously for mechanized operations. There was no difficulty experienced in cutting these materials after the operator became accustomed to the proper operating speed. Free-hand straight-line and shape cuts on $^1/_4$-in. aluminum were made with 600-amp DCRP using an HW-11 torch and a SWM-2 portable welder; these cuts are shown in Fig. 14. One objection to manual cutting is the difficulty experienced in attempting to follow a mark or line on the metal surface at the speeds required, owing to the dark lens that must be used in the welder's helmet. This can be improved somewhat by using a spotlight to light up the marking on the plate surface, or by using a deeply scribed

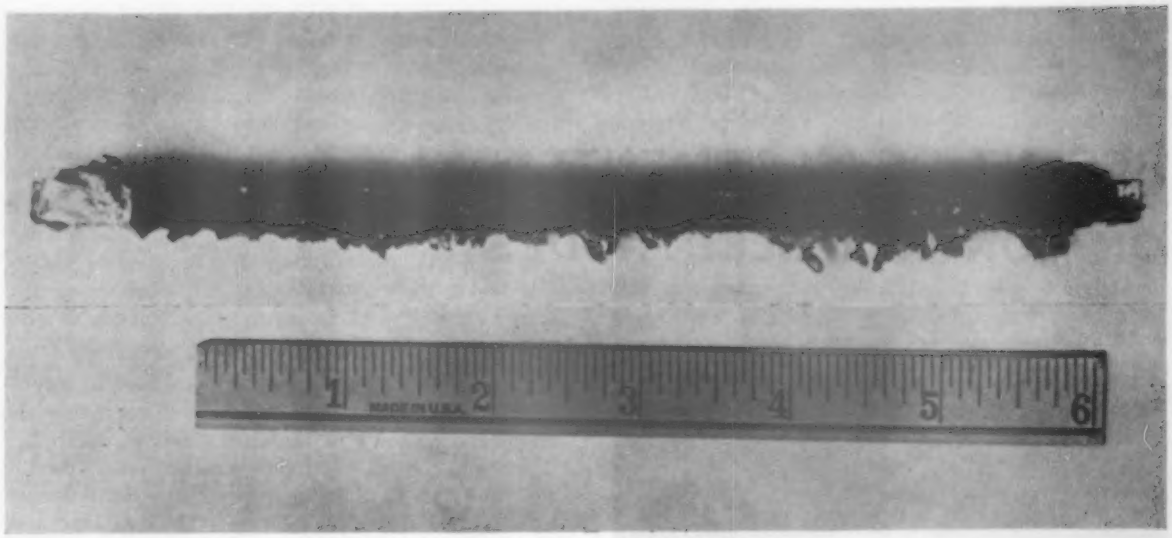

Fig. 13 Inert-gas metal-arc cut $^1/_4$-in. aluminum using carbon dioxide as shielding gas

mark, groove or a nonmetallic guide. Cuts have been made in downhand and vertical positions, but no effort has been made to check the process for overhead work.

Estimated Operating Costs

The cost of inert-gas metal-arc cutting appears to be comparable to that of cutting carbon steel with the oxygen-cutting process. Cost calculations for inert-gas metal-arc cutting $^3/_8$-in. aluminum were based on data from Table 1 as follows:

Argon—20 cfh at $0.10 per cu ft	$2.00 per hr
Power for 600-amp generator	0.50 per hr
Labor at $1.80 per hr plus 100% overhead	3.60 per hr
Fixed Charges	$6.10 per hr

Wire costs for $^3/_{32}$-in. layer wound steel wire varied from $0.20 to $0.30 per lb depending upon the type of wire used and quantities purchased. Layer wound wire is necessary to obtain satisfactory machine performance at the high rate of wire feed required. Cutting speeds were 50 ipm at 660 amp using 200-ipm wire feed; 75 ipm at 800 amp using 250-ipm wire feed; and 87 ipm at 860 amp using 300 ipm wire feed.

The total cost per foot of cut exclusive of base metal consumed in the kerf and apparatus repairs are as follows:

660 amp	$0.0435–$0.0533
800 amp	0.0322– 0.0404
860 amp	0.0306– 0.0388

In order to evaluate these operating costs with other cutting processes, a comparison was made between inert-gas metal-arc cutting on aluminum and oxygen cutting on carbon steel. The estimated cost of cutting $^3/_8$-in. carbon steel with the oxy-acetylene process under average conditions and average rates for gas and labor is approximately $0.045 per foot. This indicates that inert-gas metal-arc cutting costs are of the same order of magnitude as gas-cutting costs. From the cost standpoint and weldable quality of cut surfaces, we expect many applications for the inert-gas metal-arc cutting process in industry.

Fig. 14 Hand inert-gas metal-arc cut $^1/_4$-in. aluminum with argon shielding

Summary

Laboratory tests have shown that the inert-gas metal-arc cutting process, using a consumable steel wire electrode with direct current reverse polarity, can be successfully used to sever and shape many nonferrous metals. Cut edges suitable for welding have been made on $^1/_8$- to $^1/_2$-in. aluminum plate with standard inert-gas metal-arc welding equipment.

Inert-gas metal-arc cuts have also been made on plates of copper and nickel, and alloys of these metals. Operating costs are low in terms of consumable items and labor per foot of cut. Due to the extremely fast cutting speeds obtainable with this type of cutting, it is anticipated that the process will find extensive use in many phases of industry.

RECENT DEVELOPMENTS ON CONTACT ELECTRODES

Welding with contact type electrode

Characteristics of the contact electrode offer possibilities for cost reduction through increased deposition rate, reduced cleaning costs and greater welder appeal

BY D. L. MATHIAS

Contact or iron-powder electrodes, as they are sometimes called, have received considerable attention by the welding industry during the past year. Reaction to these electrodes has varied somewhat, but the net result has been the consumption of many millions of pounds in a span of but one year. There could be no better evidence to justify the statement that contact electrodes have found a place and are here to stay.

Before proceeding, it might be well to review the origin and meaning of the term "contact electrode." The term "contact electrode" is rather loosely used in this country. Contact electrodes have been described by van der Willigen[1] as follows: "The combination of touch welding and automatic striking and restriking has been called 'contact welding,' and the electrodes developed for this technique are called 'contact electrodes.'" Many of the iron-powder electrodes of American manufacture do not have automatic striking, or self-ignition characteristics and, strictly speaking, are not contact electrodes. However, the term "contact electrode" has been generally accepted in this country for electrodes having coatings with high metal powder content and suitable for welding with drag or touch technique, whether or not they are self-igniting.

The introduction of a new product, such as the contact electrode, is frequently accompanied by a flurry of excitement over the broad claims that are made. However, most of us have become accustomed to overemphasized claims born of enthusiasm and are willing to concede that a substantial step forward has been made even when claims are only partially verified. Such is the case with contact electrodes.

One approach on the subject of contact electrodes would be a presentation of case histories covering actual applications. So complex and varied are the many applications that time would not permit adequate coverage. Treatment of the subject from a strictly technical viewpoint would be of little value since we have only touched upon the potentialities of contact type electrodes to date and have much to learn of their mechanics of operation.

The most satisfactory approach for both producer and consumer would seem to be a review of the art setting forth the essential performance characteristics of contact electrodes as we now know them. This approach would serve to familiarize the user with their operation and properties and enable him to apply them where they will best serve his needs. Through an exchange of information and experience between electrode producer and fabricator, contact electrodes can and will be developed and applied to effect worth-while cost reductions.

A few of the questions frequently asked concerning contact electrodes, the answers to which are pertinent

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to any evaluation and understanding of their application, are: (1) What is the purpose of the metal powder addition? (2) Do they represent a new development in the field of metallic arc welding? (3) How do they differ from electrodes of conventional design? (4) What are their economic potentialities?

Every business is confronted with problems of readjustment from a wartime to a peacetime economy. All are examining their product design, grades and sources of raw materials they use, and the processes, procedures and other items that enter into the cost of their product. We have passed from a seller's to a buyer's market; a situation which serves to stimulate research and development of new and improved products.

During this transition period, it is of benefit to everyone to carefully weigh all designs, materials and processes which offer economic advantages. The value of any product or process is no greater than our understanding of the basic principles involved; of our knowledge of its possibilities, limitations, and proper use. Adverse snap judgment may delay adoption of a change that offers significant possibilities while hasty acceptance may impair an enviable reputation built up over a period of years. Almost every product which represents a radical departure from the accepted standards with which we are familiar, is bound to experience growing pains.

What Is the Purpose of the Metal Powder Addition?

The American standard of living is to a large extent dependent upon mass production at the lowest possible cost consistent with acceptable quality. Every item of expense must be carefully examined to achieve that goal, whether it be the cost of raw materials or the tools with which these materials are processed. An electrode used in the fabrication of metals is both a material and a tool. The fabricator is concerned with both its cost as a raw material, and, as a tool, with the speed, efficiency and ease with which it deposits weld metal.

To this end, the electrode designer develops an electrode with high deposition rate and deposition efficiency and at the same time, adjusts the operating characteristics to meet the fabricator's requirements for the intended applications. When an electrode reaches the fabricator, he selects the largest diameter and the highest welding current to obtain the best economy of operation. But there is a limit beyond which these efforts no longer yield the desired results.

Other things being equal, the deposition rate of an electrode is almost directly proportional to the welding current employed providing it is kept within the recommended limits for the electrode under consideration. Deposition rate is also a function of the "in-built" arc voltage of the electrode; the higher the arc voltage, the higher the deposition rate. It is possible to increase the deposition rate of most of our conventional electrodes beyond existing values by increasing arc voltage through adjustment of coating formulation. However, most electrodes have been designed to operate with the highest arc voltage that can be safely used on applications for which they were intended.

Attempts to increase deposition rate through increasing the arc voltage over these values increases depth of penetration and the evils associated therewith. It may also result in overheating of the weld deposit with abnormal loss of essential elements and seriously impair weld quality. The use of large diameter electrodes affords a means of increasing deposition rate, but this approach to effect increased welding speeds has been exhausted. With a few exceptions, the arc action of conventional electrodes becomes progressively more explosive, spatter increasingly heavier and the uniformity and smoothness of the weld deposit progressively less acceptable as electrode diameter is increased.

By adding appreciable quantities of metal powder to the coating and increasing the coating thickness, as in the contact electrode, the deposition rate may be substantially increased without introducing the objectionable characteristics just cited. Since the metal powder in the coating is not a part of the welding circuit, except in the immediate vicinity of the arc, it serves to cool the weld puddle through dilution, thereby preventing overheating with its attendant dangers. Furthermore, the conductivity of the coating in the region of the arc gives a smooth, steady arc action characteristic of a small diameter electrode. Thus, by controlling the metal powder content of the flux, its distribution in the coating and by judicious use of arc stabilizers, the thermal and electrical characteristics of the arc may be varied over a wide range. The addition of metal powder to the coating permits the use of higher welding currents than are normally used with conventional electrodes further increasing their speed advantage.

Are Contact Electrodes New?

Although contact electrodes were only accepted for regular production use in this country during the past year, they have been in use in Europe for many years. The first patent issued to cover the contact type electrode was granted to Roberts and Paterson in 1935.[2] Contact electrodes were slow to gain acceptance in Europe, but through constant education and training of users, together with improvements in electrode performance, they were gradually accepted and today contact electrodes represent a substantial percentage of European electrode consumption.

It is difficult to obtain figures on the total volume and percentage breakdown according to type for electrodes consumed in Europe since there is no association for gathering statistics comparable to the National Electrical Manufacturers Assn. (NEMA) in the United States. Considerable quantities of contact electrodes are used in some European countries, while in others there is little activity on this type electrode. In some of these countries, the major portion of one producer's output is contact electrodes; that of another's is almost exclusively electrodes of the conventional variety.

Pintard[3] estimates that of the total quantity of elec-

Table 1—Estimated Percentage Distribution of European Iron-Powder Electrodes According to Type

Type of coating	*AWS classification*	*Iron powder content of coating, 25% and over*	*5% and over*
Cellulose	E6010-6011	7	6
Rutile	E6012-6013	55	57
Low-Hydrogen	E6015-6016	20	30
Iron Oxide	E6020-6030	8	7

trodes consumed in Europe, upward of 15% contain iron powder and they are continuing to gain in popularity. While iron powder is added to the coating of some European electrodes to increase their deposition rate, it is added to the coating of others primarily to modify the characteristics of the arc. An approximate breakdown according to AWS Classification for European electrodes having coatings containing iron powder is shown in Table 1.

Contact electrodes of European design or manufacture have been examined by the American welding industry on many occasions but with little success. The fact that these efforts met with little or no success should not be considered in any sense as derogatory of this type or source of electrode. Both the iron-oxide "hot rod" and the low-hydrogen type electrode which have been eminently successful in this country were based on formulations that had their origin in Europe.

In their original form, these European electrodes were not acceptable to the American welding industry but, after modification to meet our standards of performance, they played important roles in the advancement of welding. In like manner, electrodes which have been developed here to meet our standards have, in general, found little favor in Europe. Situations of this nature merely indicate that our respective conceptions of what constitutes an acceptable balance of performance characteristics are at variance. American and European electrodes alike have served well the applications for which they were originally designed.

Based on past experiences, there is no reason to believe that contact electrodes will be an exception. They differ in their mode of operation from that of electrodes on which we have built up a considerable background of experience, but they do have possibilities that should not be overlooked. In order that we may put them to work to serve our needs, we must acquire a thorough knowledge of their mechanism of operation, and their possibilities and limitations. We may then design and apply them to meet our requirements and profit by the economic advantages they offer.

How Do Contact Electrodes Differ from Other Types?

Contact electrodes differ sufficiently from conventional electrodes that an explanation of their mechanism of operation, as we now know it, seems to be in order. The weld deposit or nugget is made up of metal derived (1) from the electrode and (2) from the plate by penetration of the arc. With most conventional electrodes, the metal they contribute to the nugget or weld comes almost entirely from the electrode core wire. In the case of carbon steel electrodes, less than 1% of the weight of the weld is derived from the coating and this consists of ferro alloys that serve as deoxidizers. Even with low-alloy electrodes of the composite variety, the amount of metallics derived from the coating seldom exceeds 5% of the weight derived from the core.

In the case of contact electrodes, the amount of metallics introduced from the covering to supplement the metal derived from the core may vary from 5 to 100% by weight of that available from the core. The presence of this amount of metal powder in the covering alters the electrical characteristics of the arc, the thermal balance in the weld area and the geometry of the electrode with respect to the work. In short, the mechanism of the arc and the pattern of base metal penetration of the contact electrode are radically different in

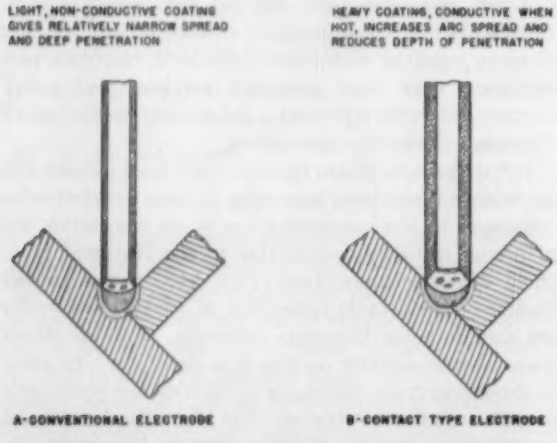

LIGHT, NON-CONDUCTIVE COATING GIVES RELATIVELY NARROW SPREAD AND DEEP PENETRATION
HEAVY COATING, CONDUCTIVE WHEN HOT, INCREASES ARC SPREAD AND REDUCES DEPTH OF PENETRATION
A-CONVENTIONAL ELECTRODE
B-CONTACT TYPE ELECTRODE

Fig. 1 Comparison of penetration characteristics of conventional and contact type electrodes

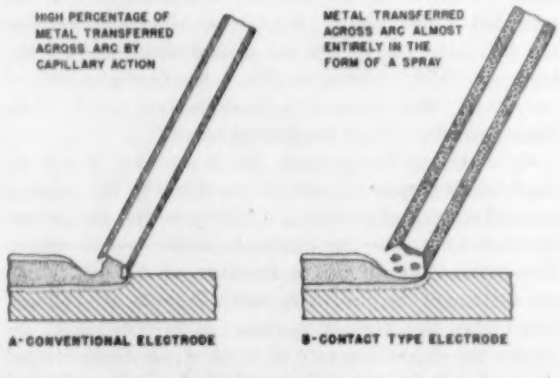

HIGH PERCENTAGE OF METAL TRANSFERRED ACROSS ARC BY CAPILLARY ACTION
METAL TRANSFERRED ACROSS ARC ALMOST ENTIRELY IN THE FORM OF A SPRAY
A-CONVENTIONAL ELECTRODE
B-CONTACT TYPE ELECTRODE

Fig. 2 Metal transfer characteristics of conventional and contact type electrodes

character from those of the conventional electrodes we have been using. Figure 1 illustrates typical penetration characteristics for conventional and contact electrodes. The penetration pattern for conventional electrodes is generally narrower and deeper than that of the contact electrode.

Most electrodes of conventional types are designed for use with a free arc. Few of them can be used with drag technique without shorting or sticking unless abnormally high welding currents are used. The flux crucible at the arcing end of conventional electrodes is rather shallow by comparison with that of contact electrodes and the major portion of the molten core wire is transferred across the arc by capillary action during which time the arc is momentarily short circuited. If the arc length is shortened, as is the case when drag technique is used, the short circuit interval may be increased to the point where metal in transit from electrode to work freezes and results in complete arc extinction.

By increasing the coating thickness or altering its refractoriness, crucible depth and arc voltage could be increased, and the character of metal transfer across the arc progressively changed from globular to spray type. An increase of coating thickness would permit the use of drag technique with conventional electrodes without danger of sticking but it would be accompanied by excessive penetration, deep undercut and heavy spatter. In addition to these objectionable characteristics, an increase in the distance from tip of the electrode core wire to the work side of the arc due to the deep crucible would result in frequent arc outages, particularly with low open-circuit voltage.

Under normal welding conditions, the arc of most conventional electrodes is intermittently short circuited as metal is transferred from core to work, i.e., the arc alternates periodically from short circuit to free arc as illustrated by *A* and *B*, respectively, Fig. 2. This is generally referred to as globular transfer. In contrast to this, most of the metal transferred across the arc of a contact electrode is in the form of small drops without bridging the arc gap. This is what is known as spray transfer and is shown by *B*, Fig. 2. A more detailed explanation of the mechanism of metal transfer for contact electrodes is given by van der Willigen.[1]

Contact electrodes operate with a crucible that is relatively much deeper than that of any conventional electrode. While the depth of the crucible may be partly due to the higher current values used with contact electrodes than with conventional electrodes, the coating thickness and composition are intentionally adjusted to accomplish this condition. Unlike their conventional counterpart, the deep crucible of the contact electrode does not result in an unusually high arc voltage. For example, the arc voltage of a contact electrode may vary from a value comparable to that of the conventional variety, as in the case of the iron-oxide electrodes, or it may be somewhat higher than the conventional counterpart, as in the case of rutile electrodes.

What Are the Economic Potentialities of Contact Electrodes?

Theoretically, contact electrodes offer possibilities for substantial cost reductions on many applications. On a wide variety of work, they have been highly successful and have resulted in marked reduction of welding costs. On others, they have failed to show any advantage over conventional electrodes. This situation was not unexpected for the contact electrode is not a panacea nor a cure-all.

To what extent contact electrodes will be successfully used on a multiplicity of applications as yet only superficially covered, or not yet tried at all, depends on many factors. The nature of the application, the conditions under which tests are conducted, the composition of the base metal and the characteristics of the electrodes are all determining factors. It has been necessary to provide modifications of every class of conventional electrode to meet certain groups of applications. It will be necessary to provide contact electrodes with comparable modifications to suit similar applications and still maintain their economic advantages.

For any potential application, contact electrodes possess several intangible advantages that might easily be overlooked in simple cost studies. These intangibles offer cost reductions that are not easily calculated and actual production trials may be required to bring out the advantages of contact electrodes over those of the conventional type. Among the intangible advantages are the ability to use drag technique on many applications, and the steady spray-type arc action with which it operates. Both of these appreciably reduce operator fatigue. In addition, smooth, uniform welds and low spatter loss reduce cleaning costs and add materially to the appearance of the finished product.

Tentative AWS-ASTM Classification Numbers for Contact Electrodes

Due to the fact that contact electrodes have only come into use during the past year, no specifications, and therefore no classification numbers, are as yet available. In the absence of suitable specifications, the Welding Industry has been forced to use the manufacturers' trade designation or to refer to them as rutile contact electrodes, iron oxide contact electrodes, etc. The AWS-ASTM Filler Metal Committee is currently preparing specifications for contact electrodes and has reserved classification numbers for purposes of identification. These proposed numbers, together with the existing classification numbers for their conventional counterpart are listed in Table 2. These tentative classification numbers, without the prefix "Proposed," will be used for the remainder of this paper.

Operating Characteristics

Although E6014, E6024, E6027 and contact low-hydrogen electrodes are currently available, major interest has so far been centered on E6024 electrodes. This is but natural since rutile electrodes constitute roughly half of the total volume of all carbon-steel

Table 2—AWS-ASTM Classification Numbers for Covered Arc-Welding Electrodes

Proposed numbers for contact-type electrode	*Existing numbers for corresponding conventional electrode*	*Type of covering*	*Type of current*
6014	6013	Rutile	AC or dc
6024	6012	Rutile	AC or dc
6027	6020	Iron oxide	AC or dc
Not yet reserved	6016	Low-hydrogen	AC or dc

and low-alloy electrodes consumed in this country. Increasing attention is being given to the E6027 type but because of the high deposition rate and relatively low volume of E6020 electrodes, it has not so far aroused the same interest received by E6024 electrodes. The E6014 and contact low-hydrogen electrode show considerable promise, but as yet they are relatively untried in this country.

Contact electrodes, as the name suggests, were intended to be used with the electrode coating held in contact with the work and dragged along the joint in the direction of welding. When so used, no control of arc length is required since the electrode is designed to operate with optimum arc length, or arc voltage, at the recommended current. Very good results may be had on fillet and lap welds when drag technique is employed, but contact electrodes may also be used with a free arc. Some operators prefer to use a free arc as it permits freedom of manipulation to control the slag and gives a weld of somewhat better contour than that obtained with drag technique. Contact electrodes work well with either procedure, the choice of procedure rests with the operator or fabricator, depending upon which best suits the application at hand.

When contact electrodes are used for groove welds, a short free arc is recommended in preference to drag technique. A free arc gives better sidewall wash and permits weaving the electrode which is usually necessary on groove welds. Weaving makes it possible to reduce the number of passes or layers required to complete a weld, thereby minimizing distortion.

Both the E6024 and E6027 electrodes operate with a smooth, steady arc and spray-type metal transfer. Spatter loss is extremely low in both cases, slag removal is good and the welds are flat and uniform with good wash at the sidewalls. Welds deposited with contact electrodes are generally free of undercut. Under some conditions, a slight wash or sloughing out may be experienced along the upper edge or vertical leg of horizontal fillets but the junction of weld and plate usually has a smooth, rounded contour rather than a sharp, re-entrant angle.

A characteristic frequently associated with contact electrodes is self-ignition of the arc upon bringing the electrode coating into contact with the work. This may or may not, be a desirable feature and there are several aspects to be considered when passing judgment on this matter. No difficulty is experienced in establishing an arc with an unused electrode as the core is exposed at the striking end. Ease of restriking an arc with a partially used electrode may vary with the temperature of the electrode, the particular electrode in use, its diameter and source of power. Some electrodes will restrike after cooling to room temperature whereas others will restrike only when hot. Some makes or grades of electrodes will restrike easier in the small diameters than in the large. Other conditions being the same, the higher the open-circuit voltage, the greater the ease of restriking.

Even though some difficulty may be experienced on restriking, it should not be considered seriously objectionable for such is the case with many of the conventional electrodes. When an arc cannot be struck with a partially used electrode, it is a simple matter to pinch or gently break the flux crucible so as to expose the core.

An electrode with a coating sufficiently conductive to be self-igniting under most conditions may pose far more serious problems than ease of striking. If inadvertently allowed to touch work, jigs or fixtures, an electrode with self-arcing characteristics might result in arc-flash or burns to the operator, or damage to work or equipment.

Deposition Characteristics of Contact Electrodes

When first subjected to evaluation in this country, contact electrodes with various basic types of coatings were tested. None of these electrodes measured up to our standard of performance with respect to operating characteristics. All were of European design or origin since it was there that the iron-powder electrode was conceived.

The first conventional electrode of European design to gain acceptance in this country was the iron-oxide or "hot rod" type, later identified as AWS-ASTM E6020. This electrode, after modification to meet our needs, came into widespread use during the early thirties and represented a big step forward in metallic arc welding because of its high deposition rate. It was more than coincidence that the first European contact electrode to show promise in this country was of the iron-oxide variety.

Theoretically, the deposition rate of an electrode with iron powder added to the coating should be increased in proportion to the amount of iron powder present. When the deposition characteristic of early contact electrodes were compared with their conventional counterpart, actual deposition rates were at variance with those theoretically possible. What was not fully appreciated at the time was that the modifying effect of the iron powder coupled with the characteristics imparted by European coating formulation resulted in disappointingly low deposition rates. The net result was that their relatively small speed advantage, combined with their high cost, ruled them out of consideration.

Figure 3 illustrates the relative deposition rate of the European $^1/_8$-in. diam E6027 type electrode with that of European and American $^1/_8$-in. diam E6020 type elec-

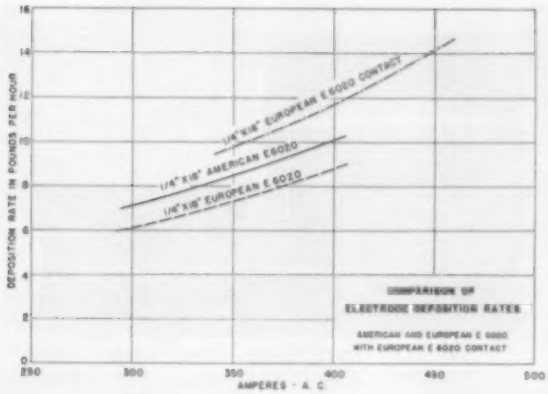

DEPOSITION RATE IN POUNDS PER HOUR
AMPERES - A. C.
1/4" X18" EUROPEAN E 6020 CONTACT
1/4" X18" AMERICAN E6020
1/4" X18" EUROPEAN E 6020
ELECTRODE DEPOSITION RATES
AMERICAN AND EUROPEAN E 6020
WITH EUROPEAN E 6020 CONTACT

Fig. 3 Deposition rate comparison of American and European E6020 or iron-oxide electrodes

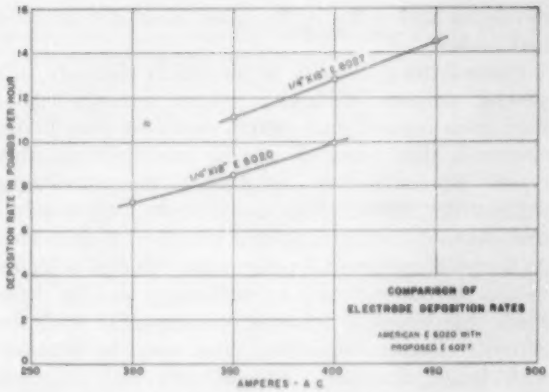


Fig. 4 Deposition rate comparison of American E6020 and E6027 electrodes

trodes at the time the early tests were made. The data presented in these curves were for alternating current and represent composite values for the electrodes then available. It will be noted that, between 350 to 400 amp, the European E6027 electrode is approximately 32% faster than the European E6020 type electrode, but only about 15% faster than the American E6020 electrode. Following the general pattern of electrode design in this country, i.e., maximum deposition rate consistent with high-quality weld deposit, American E6027 type electrodes have been developed with deposition rates in excess of those of European design. Figure 4 compares the deposition rates of American $^1/_4$-in. diam E6027 and E6020 electrodes. Between 350 and 400 amp, the deposition rate for the contact electrode is approximately 30% above that for the conventional electrode. This gain of E6027 over the E6020 warrants serious consideration by the welding industry.

An interesting feature of the contact-type electrode, when compared with the conventional electrode, is the reversal in deposition rate values upon changing from alternating current to straight polarity, direct current. Most conventional electrodes suitable for use with either ac or dc show a significantly higher deposition rate for straight polarity, direct current than for alternating current. Figure 5 shows that the deposition rate for $^1/_4$-in. diam E6020 electrodes is about 12% faster for straight polarity, direct current than for alternating current. Figure 6 shows that the deposition rate for $^1/_4$-in. diam E6027 electrode is approximately 8% slower for straight polarity, direct current than for alternating current. Regardless of classification, all contact electrodes so far tested by this author have shown the same trend. When direct current was more extensively used than at present, this trend would have been considered a serious drawback. However, with increasing use of alternating current, this characteristic of contact electrodes no longer poses a serious threat to their use.

In volume of contact electrodes consumed both here and abroad, the rutile type has so far been the most

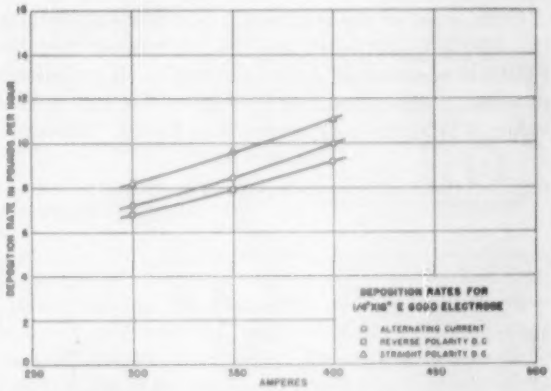


Fig. 5 Influence of power supply on deposition rate of E6020 electrodes

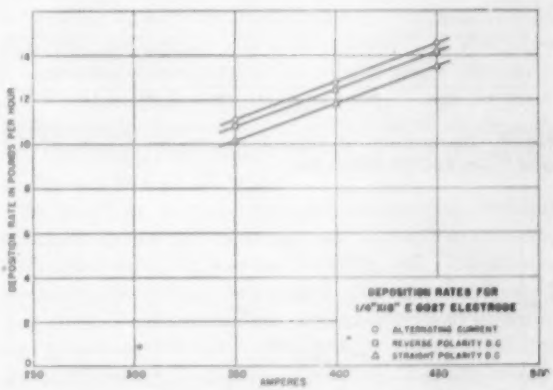


Fig. 6 Influence of power supply on deposition rate of E6027 electrodes

popular. This is as would be expected in view of the popularity of rutile electrodes of the conventional variety. In Europe, the rutile type contact electrode represents somewhat over 50% of the total volume of contact electrodes used. In this country at present, it represents almost the total volume consumed but we can expect the situation to change as other types are

developed and industry becomes familiar with their performance.

Beyond the popularity of the E6024 electrode as a general purpose electrode, greater economic gains have been realized with E6024 electrodes over E6012 electrodes than presently appear possible with other types. Several factors contribute to this outstanding superiority. E6012 electrodes are relatively low-current electrodes when compared with E6020 electrodes. As the welding current is progressively pushed to higher values, the coating tends to break down and the deposition rate ceases to increase proportionally with the current. Higher deposition rates may be obtained with larger diameter electrodes but with impaired arc action and an increase in spatter loss. For many applications, there has been a definite need for a faster general-purpose electrode such as we now have in the E6024 electrode.

From some of the statements just made concerning the E6012 electrode it may be interpreted that the E6012 is regarded as a slow electrode. If considered in terms of deposition rate for a given size and current value, it is appreciably slower than E6020. However,

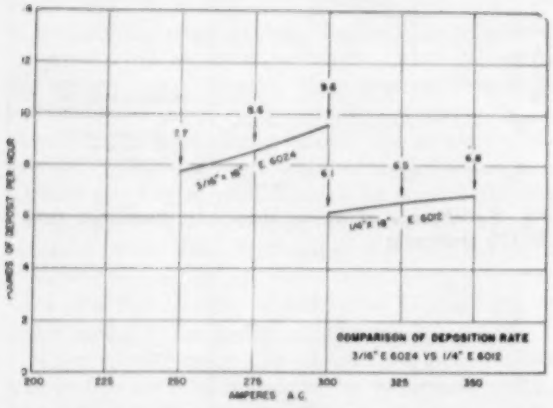


Fig. 7 Comparison of deposition rates for $^3/_{16}$-in. E6024 and $^1/_4$-in. E6012 electrodes

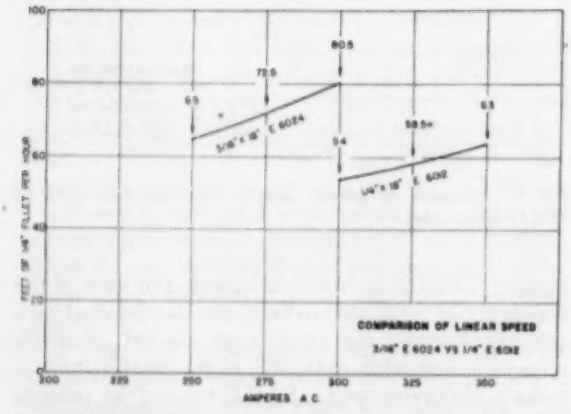


Fig. 8 Comparison of linear speeds for $^3/_{16}$-in. E6024 and $^1/_4$-in. E6012 electrodes

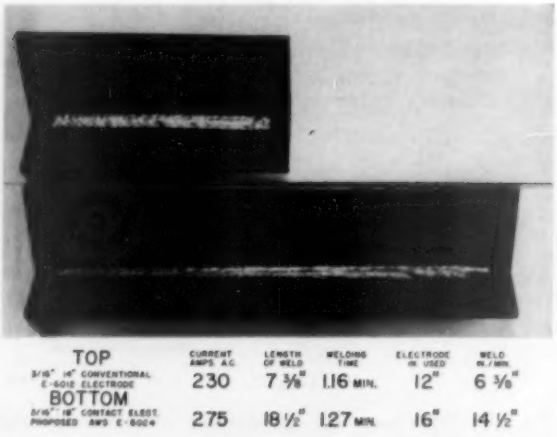


Fig. 9 An example of the speed superiority of $^3/_{16}$-in. E6024 electrode over $^3/_{16}$-in. E6012 electrode on $^1/_4$-in. fillet welds

for a wide variety of applications, it actually results in higher welding speeds than are attainable with E6020. Because of its relatively cold arc, E6012 electrodes may be successfully used on light work and poor fit-ups. Its shallow penetration permits welding on a greater variety of steels than E6020 without danger of weld cracking or reaction pitting. On such applications it would be necessary to reduce the current for E6020 to a point where its deposition rate would be below that for E6012 at its optimum current.

Many of the advantages of E6012 electrodes have been carried over to the E6024 or rutile contact electrode, but with a marked increase in deposition rate. The relative deposition rates on alternating current for $^3/_{16}$-in. diam E6024 and $^1/_4$-in. diam E6012 electrodes are shown in Fig. 7. The increase in deposition rate of the E6024 electrode over that of the E6012 electrode is greater than for any other type contact electrode over its conventional counterpart. This superiority in deposition rate expressed in terms of linear feet of $^1/_4$-in. fillet weld per hour is illustrated in Fig. 8. A still better visualization of this superiority is shown in Fig. 9. In this example of the advantage of E6024 over E6012, 14$^1/_2$ in. of $^1/_4$-in. fillet weld were deposited per minute with the E6024 electrode as compared to 6$^5/_8$ in. for the E6012 electrode.

While substantial cost reductions have been affected on many applications by the use of E6024 electrodes, there are other applications for which the currently available electrodes are not suitable. On high carbon or some low-alloy steels, weld cracking may be experienced due to high dilution. The macrograph of a horizontal fillet shown in Fig. 10 illustrates the high dilution characteristic of E6024 electrodes when used at their optimum current value. In this case, dilution is about 50% compared to 10 to 15% for E6012 electrodes when used at their optimum current.

Although E6024 electrodes are appreciably faster than E6020 electrodes for a given diameter and current

Table 3—Effect of Composition on Tensile Properties of Welds Deposited with $^3/_{16}$-In. Diam E6024 Electrodes—$^3/_4$-In. Plate—AWS-ASTM Joint Design—275 Amp A-C, Condition—As-Welded and Unaged

Electrode	Yield, psi	Ultimate, psi	Elongation, % in 2 in.	Reduction of area, %	Percent C	Mn	Si
A	74,750	88,200	0	0	0.08	0.98	1.29
B	74,550	87,300	2.0	20.5	0.09	0.90	1.09
C	76,625	86,750	16.4	27.0	0.07	0.86	0.78

value, it must be borne in mind that E6020 electrodes, under identical conditions, are faster than E6012 electrodes. Thus, if we compare $^1/_4$-in. diam E6024 electrodes with $^1/_4$-in. diam E6012 electrodes at 350 amp ac (see Fig. 11) the former is approximately 70% faster than the E6012. However, if the same comparison is made between $^1/_4$-in. diam E6024 and $^1/_4$-in. diam E6020, the former is only about 40% faster than E6020. Obviously, substitution of E6024 electrodes for E6020 electrodes would not show the same economic gain as substitution of E6024 for E6012 unless there was some specific advantage for such a change.

On applications where reaction pitting or weld cracking is experienced with E6020 electrodes, E6024 electrodes may be successfully substituted providing their mechanical properties are acceptable for the application. An application of this nature will result in a worthwhile cost reduction.

Mechanical Properties

The quality of welds deposited with iron-powder or contact electrodes compares favorably with the quality obtained with electrodes of conventional design. When analyzing the mechanical properties of welds deposited with contact electrodes, it is well to bear in mind that, as yet, no specifications are available that were written specifically to evaluate their performance. As a result, many different procedures were employed in early investigations and it was almost impossible to compare the results obtained by various laboratories for any given electrode. For the same reason, it was equally difficult to evaluate the relative performance value of contact electrodes with electrodes of conventional types. To add to an already complex and confusing situation, the chemistry, and therefore the mechanical properties of welds deposited with contact electrodes was undergoing adjustment.

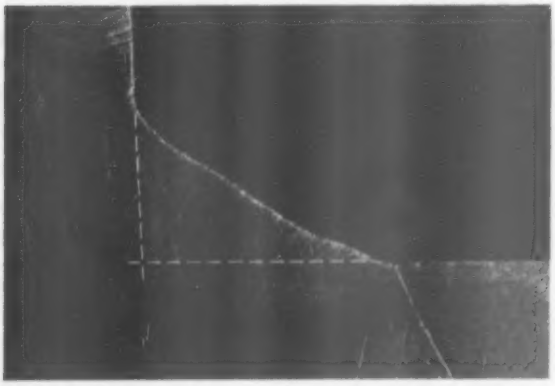


Fig. 10 Macrograph of horizontal fillet weld deposited with $^3/_{16}$-in. E6024 electrode showing high dilution ratio

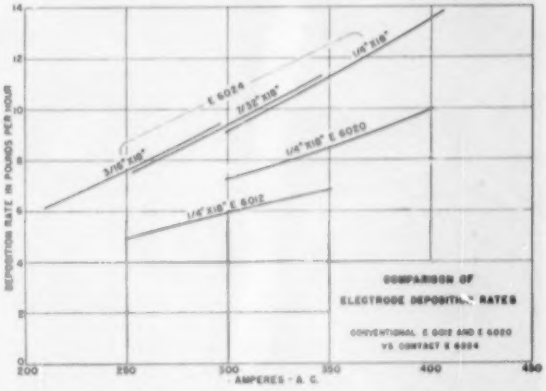


Fig. 11 Comparison of deposition rates for E6012, E6020 and E6027 electrodes

One of the first questions that came up with the introduction of contact electrodes pertained to the correct procedure for welding test plates for evaluation of weld quality. Those who prepared test plates at that time were of the opinion that test welds should be deposited with straight progression beads using drag technique to simulate actual production conditions. Fantastically low ductilities were obtained with some of the early E6024 contact electrodes used with this procedure and, as a result, there were some misgivings as to the acceptability of this type electrode.

In an effort to determine the influence of welding variables on mechanical properties, ductility in particular, other procedures were investigated. To many, the net result of these tests were confusing and indicated that contact electrodes were extremely critical to welding procedure. What was not fully appreciated by many who were conducting tests was that the chemistry of the weld deposit was undergoing adjustment concurrently with their test programs. An example of the change in chemistry of the weld deposit and its effect on mechanical properties is shown in Table 3. While the ductility of the weld deposit increases progressively with reductions in the manganese and silicon content, reduction in silicon is primarily responsible for the improvement shown.

It was previously stated that high weld dilution from the base metal may, in some cases, be detrimental to weld quality. In other cases, weld dilution may be

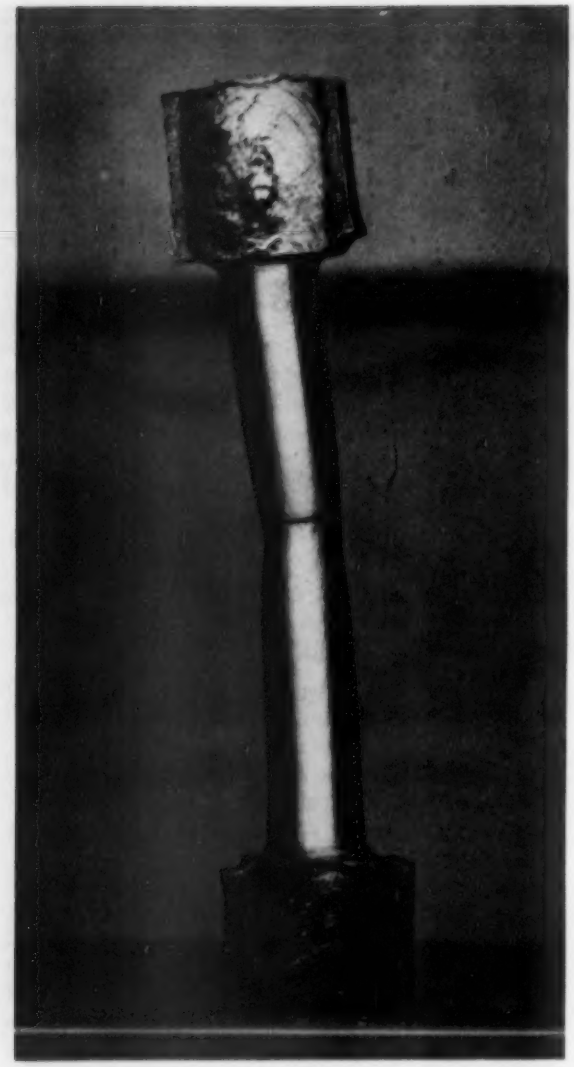


Fig. 12 High dilution improved ductility on this unorthodox specimen cut from weld deposited with 3/16-in. E6024 electrode

beneficial if we are concerned with ductility of the deposit beyond the values obtained with AWS-ASTM test procedure. The ductility obtained with electrode C, Table 3, is fairly representative of E6024 weld deposits when tested in the usual manner. The composition of the weld from this electrode differs considerably from that obtained with most conventional electrodes, particularly with respect to the silicon content.

High silicon in weld deposits frequently has an adverse effect on ductility, especially when the Mn/Si ratio approaches or exceeds unity. An interesting example of the beneficial effect of weld dilution is shown by the 0.505-in. tensile specimen in Fig. 12. This specimen is of an unorthodox variety. It was machined from a 3/8-in. plate upon which two straight progression beads were deposited in line with each other but on opposite sides of the plate. They were deposited with 3/16-in. diam E6024 electrodes using 275 amp ac. Most of the reduced portion of the specimen consists of weld deposit. Elongation for each of two specimens in the as-welded and unaged condition was 23% in 2 in.

An examination of the specimen reveals an absence of tears or incipient cracks in contrast to specimens machined from standard test plates. Improvement in ductility resulted from base metal dilution of the weld which, in this case, was about 50%. Welds of composition C, Table 3, when deposited on 0.50% manganese and 0.05% silicon base metal, are altered by dilution to 0.68% manganese and 0.41% silicon. These data are presented only as an indication of the beneficial effect of dilution when E6024 electrodes are used for single-pass fillet and lap welds on the general run of mild steel.

While several types of contact electrodes have been offered to the welding industry, the remarks that follow are confined largely to the effect of welding procedure on the mechanical properties of welds deposited with E6024 contact electrodes. Although the actual tensile properties obtainable with currently available contact electrodes of the rutile variety differ somewhat from those of conventional electrodes, the differences are only one of degree. The response of tensile properties to variations in welding procedure follows the same pattern that has been observed with conventional electrodes.

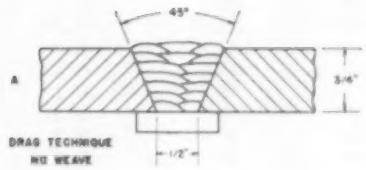
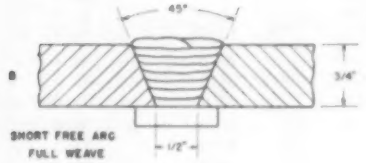
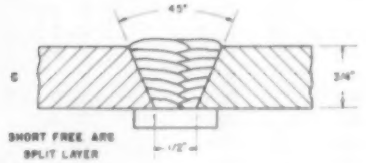
The lack of specifications setting forth testing procedures and minimum performance requirements has been a contributing factor to the widely differing results obtained by various laboratories on their evaluation of contact electrodes. It has also served to eliminate the use of contact electrodes on those weldments where compliance with specification requirements is rigidly enforced. On the other hand, it would be impossible to prepare an acceptable specification for a product or process for which inadequate performance data were available. In order that an appropriate specification may be prepared to cover the performance and application of contact electrodes, both producers and consumers of contact electrodes have been working with the AWS-ASTM Filler Metal Committee. Extensive programs were initiated for the purpose of securing adequate test data to facilitate and expedite the use of contact electrodes by the welding industry.

When programs for evaluating the influence of welding variables on the performance characteristics of contact electrodes were planned, the generally known variables were listed for investigation. These included drag technique versus free arc, split layer versus full weave and preheat and interpass temperature conditions. In addition to these, one variable long recognized as having a marked influence on the ductility of weld deposits, but not quite as generally known as those mentioned above, was also listed for investigation. This is the influence of aging, i.e., temperature and length of time test specimens are held between completion of machining and testing.

Laboratory schedules vary considerably depending upon work load, priority ratings on projects, etc., Thus, high priority projects requiring determination of

Table 4—Effect of Technique on Tensile Properties of Welds Deposited with $^{3}/_{16}$-In. Diam E6024 Electrodes

3/4" Plate, AWS-ASTM Joint Design - 275 Amperes A.C.
Condition - As Welded and Unaged

	Yield psi	Ultimate psi	Elong. % in 2"	% Red. of Area
 A	74,800	85,400	16.5	28.2
	74,425	88,050	16.3	25.7
	Av. 74,613	Av. 86,750	Av. 16.4	Av. 27.0
 B	69,575	80,075	16.3	24.2
	70,300	79,775	15.5	27.1
	Av. 69,938	Av. 79,925	Av. 15.9	Av. 25.7
 C	69,175	81,300	13.8	26.6
	71,550	81,900	15.3	24.1
	Av. 70,363	Av. 81,600	Av. 14.6	Av. 25.4

tensile properties may be temporarily put aside to permit solution of emergency problems. Test plates and tensile specimens in various stages of completion may be held up for indefinite periods. Not infrequently, little consideration is given to the temperature of the specimens or the length of time they are held during these periods of delay. When work is resumed on the project of which such specimens are a part, test values frequently show no recognizable relation to the variables explored.

The property upon which the most erratic results are observed is ductility as expressed by elongation and reduction. Relaxation of stresses and release of hydrogen are both considered beneficial to ductility. Most of the evidence available points to release of hydrogen on aging as the major factor contributing to improvement in ductility.

Hydrogen, which is present in varying amounts in the shielding atmosphere of coated electrodes, is highly soluble in the deposit during welding. Its solubility is much lower for steel in the solid state than for the liquid state. As the weld puddle solidifies, a substantial amount, but not all, of the hydrogen is evolved. Immediately after cooling to room temperatures, sufficient hydrogen may be retained in steel to build up tremendous pressures within mechanical discontinuities in the weld deposit.

The presence of hydrogen in steel is revealed by fisheyes, microfissures and flakes. Fisheyes, as observed on the fracture of test specimens, do not exist in the weld deposit until it is subjected to plastic deformation. They develop during plastic deformation of the tensile specimen if the pressure of hydrogen retained in voids is high enough to cause premature rupture of the metal adjacent to the void.

The presence of sufficient hydrogen to result in the formation of fisheyes will lower the ductility of weld deposits but will have little, if any, effect on the yield point and ultimate strength. Aging under suitable conditions will lower the hydrogen content and reduce the magnitude of fisheyes or eliminate them entirely. Most of the hydrogen retained after solidification is slowly evolved, the rate of hydrogen evolution being a function of time and temperature. Weeks of aging at room temperature may be required to show a significant improvement in ductility while only 24 to 48 hr aging at 200–220° F are required to effect a marked increase.

Microfissures and flakes, when observed, do exist as defects in unstressed metal and cannot be eliminated by thermal treatment alone. The excellent response of E6024 electrode deposits to aging, as exhibited by the marked increase in ductility, is evidence that the presence of hydrogen exerts only a temporary influence on the mechanical properties of the weld deposit.

Effect of Welding Technique

Table 4 shows the effect of technique on the mechanical properties of welds deposited with $^{7}/_{32}$-in. diam E6024 electrodes using 325-amp a-c standard AWS-ASTM test plates, $^{3}/_{4}$ in. thick, with 45-deg included angle and $^{1}/_{2}$-in. root gap were used. The preheat and interlayer temperatures were 212° F. The first test plate was welded using drag technique and straight progression without weaving. The second plate was essentially the same as the first except for a short free

Table 5—Effect of Welding Procedure and Aging on Tensile Properties of Butt Welds Deposited with $^{7}/_{32}$-In. E6024 Electrode—$^{3}/_{4}$-In. Plate—AWS-ASTM Joint Design—325 Amp AC

Test No.	Aging	212° at start of each	Yield, psi	Ultimate, psi	Elongation, % in 2 In.	Reduction of area, %
6792, full weave	None	Layer	71,200	79,450	15.5	19.8
			70,400	79,650	15.5	24.1
			*70,800**	*79,550*	*15.50*	*21.95*
6795, full weave	48 hr at 212° F	Layer	64,400	77,400	23.5	41.0
			66,600	77,350	25.0	41.3
			65,500	*77,375*	*24.25*	*41.15*
6798, full weave	15 days, R. T.	Layer	69,600	78,850	20.0	28.2
			68,350	77,850	20.0	30.2
			68,975	*78,350*	*20.0*	*29.2*
6793, split layer	None	Layer	66,900	78,900	13.5	25.5
			67,900	79,400	15.0	23.8
			67,400	*79,150*	*14.25*	*24.65*
6796, split layer	48 hr at 212° F	Layer	65,900	79,650	20.0	34.7
			69,400	79,650	24.0	45.1
			67,650	*79,650*	*22.0*	*39.90*
6799, split layer	15 days, R. T.	Layer	68,850	77,100	17.0	30.6
			67,750	75,800	15.5	25.1
			68,300	*76,450*	*16.25*	*27.85*
6794, split layer	None	Pass	71,150	82,150	15.0	21.0
			74,150	82,650	15.0	22.7
			72,650	*82,400*	*15.0*	*21.85*
6797, split layer	48 hr at 212° F	Pass	72,150	81,900	22.5	37.2
			72,400	81,900	22.0	37.2
			72,275	*81,900*	*22.25*	*37.20*
6800, split layer	15 days, R. T.	Pass	72,400	80,150	17.5	23.4
			73,650	80,650	19.0	35.0
			73,025	*80,400*	*18.25*	*29.2*

* Italic figures denote average of group.

arc. This resulted in a slightly wider bead, and therefore, a smaller number of passes. The third plate was welded using a short arc and full weave.

All tensile values for this group of plates were determined on 0.505-in. all-weld metal specimens in the as-welded and unaged condition. The ductilities for all plates are essentially the same. Except for moderate variations in yield point and ultimate strength due to variations in technique, there are no other significant differences.

Effect of Welding Procedure and Aging

Table 5 shows the effect of width of weave, interpass temperature and aging on the tensile properties of welds deposited with $^{7}/_{32}$-in. diam E6024 electrode using 325 amp ac. It covers three groups of three plates each. All three plates in the first group were welded using full weave and an interlayer temperature of 212° F. The second group was welded using split layers and an interlayer temperature of 212° F. The third group was also welded using split layers, but with an interpass rather than an interlayer temperature of 212° F.

From each group of test plates, one set of two 0.505-in. all-weld metal specimens was tested in the unaged condition, i.e., within 16 hr after completion of welding. The second set of 0.505-in. specimens from each group was aged after machining for 48 hr at 212° F. The third set of 0.505-in. specimens from each group was aged after machining for 15 days at room temperature which varied from 70 to 80° F.

To summarize the results of the tensile tests, the yield point and ultimate strength for all plates in the first two groups are essentially the same and show no significant variation as a function of width of weave. All specimens from the third group welded with an interpass, rather than an interlayer, temperature of 212° F show a moderate increase in yield point and ultimate strength over the values for the first two groups.

The outstanding difference in the mechanical properties of all groups is the effect of aging on ductility. Elongation in the unaged condition shows little variation as a function of welding procedure. However, as a function of aging, 48 hr at 212° F results in an average increase in elongation of more than 50% over the unaged value. Room temperature aging for 15 days results in an average increase in elongation of 20% over unaged values.

On specimens subjected to aging, there is a noticeable reduction in the number and size of fisheyes on the fracture, and tears on the outside machined surface.

If we analyze the mechanical properties of welds deposited with E6024 electrodes with those of E6012 electrodes, we find that they compare quite favorably. It has long been the practice to think of ductility in terms of tensile strength; the higher the tensile strength, the lower the ductility. For a given grade and condition of material, the product of tensile strength and elongation over a reasonable range of values remains essentially constant.

If an acceptable elongation can be established for a given tensile strength, it would then be possible to

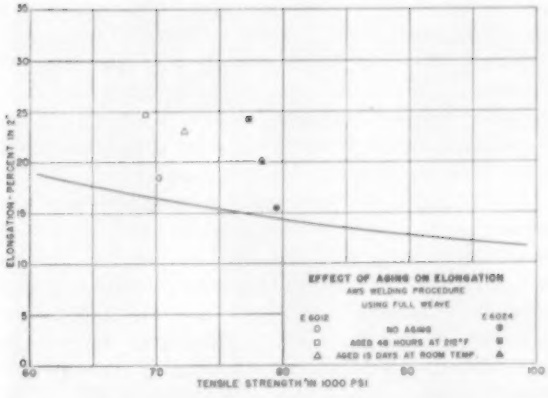


Fig. 13 Comparison of ductility of unaged and aged tensile specimens deposited with $^{7}/_{32}$-in. E6012 and E6024 electrodes using full weave

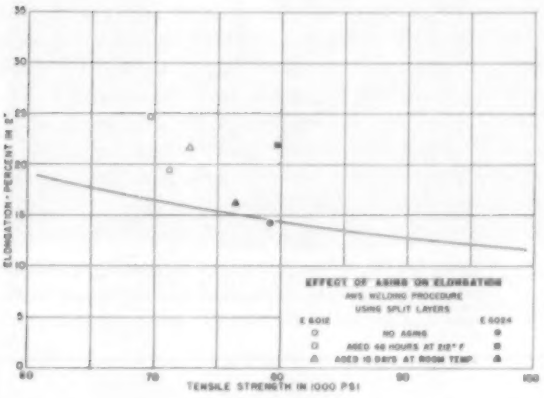


Fig. 14 Comparison of ductility of unaged and aged tensile specimens deposited with $^{7}/_{32}$-in. E6012 and E6024 electrodes using split weave

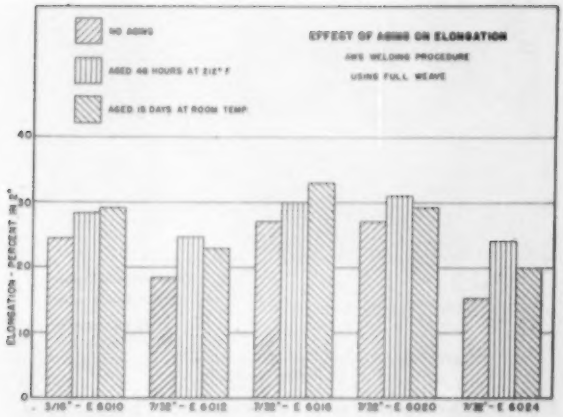

NO AGING
AGED 48 HOURS AT 212° F
AGED 15 DAYS AT ROOM TEMP.
EFFECT OF AGING ON ELONGATION
AWS WELDING PROCEDURE
USING FULL WEAVE
ELONGATION - PERCENT IN 2"
3/16" - E 6010
7/32" - E 6012
7/32" - E 6016
7/32" - E 6020
7/32" - E 6024

Fig. 15 Effect of aging on ductility of welds deposited with various types of conventional electrodes using full weave

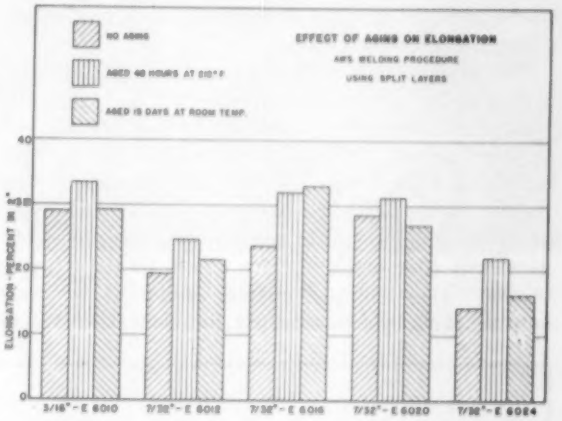

NO AGING
AGED 48 HOURS AT 212° F
AGED 15 DAYS AT ROOM TEMP.
EFFECT OF AGING ON ELONGATION
AWS WELDING PROCEDURE
USING SPLIT LAYERS
ELONGATION - PERCENT IN 2"
3/16" - E 6010
7/32" - E 6012
7/32" - E 6016
7/32" - E 6020
7/32" - E 6024

Fig. 16 Effect of aging on ductility of welds deposited with various types of conventional electrodes using split weave

calculate the minimum acceptable elongation corresponding to any other tensile strength providing we do not stray too far afield. The minimum elongation and tensile strength set forth in AWS-ASTM Specifications for E6012 provides a basis for this purpose. Using the product of these values as a constant, the curves shown in Figs. 13 and 14 graphically illustrate the minimum elongation corresponding to any given tensile strength. Figure 13 compares the unaged and aged elongation values for E6012 and E6024 using full weave. Figure 14 compares the unaged and aged elongation values for E6012 and E6024 using split layers. It will be noted that, with one exception, all elongation values for the E6024 electrode regardless of aging condition are above the curve.

Improvement in ductility upon aging is not peculiar to E6024 or other contact electrode weld deposits. The deposits of all types of conventional electrodes respond to aging as indicated by increase in elongation values. This is shown by the bar graph Fig. 15 for full weave welds. Similar results are shown in Fig. 16 for split layer welds. Aging for 48 hr at 212° F results in a substantially greater improvement in elongation than aging 15 days at room temperature. This relationship has been established for a large number of tests. There are a few exceptions in the bar graphs which do not follow this pattern. The values shown are the average of only two specimens for each con-

Table 6—Effect of Stress Relieving on Tensile Properties of Welds Deposited with $^{5}/_{16}$-In. E6024 Electrodes—$^{3}/_{4}$-In. Plate, AWS-ASTM Joint Design—275 Amp AC—Stress Relief, 1 Hr at 1150° F

Condition	*Yield, psi*	*Ultimate, psi*	*Elongation, % in 2 in.*	*Reduction of area, %*
As-welded	71,800	80,800	17.0	22.8
	70,550	81,300	22.5	34.8
Stress relieved	67,650	81,650	25.5	43.2
	69,750	81,800	29.0	61.6

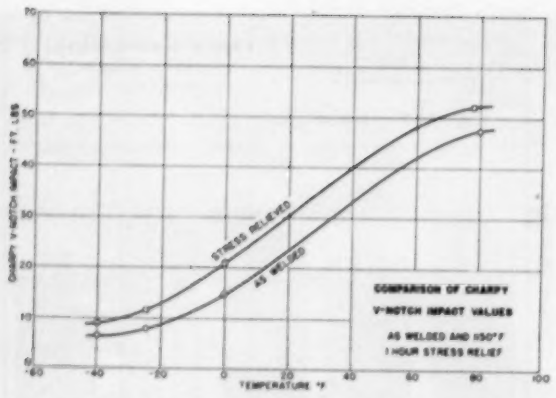


Fig. 17 As-welded and stress-relieved Charpy V-notch impact values for butt welds deposited with $^{5}/_{16}$-in. diam E6024 electrodes

dition. One abnormal specimen in any plate in a series of tests of this nature may alter the normal pattern of response to aging.

Welds deposited with E6024 electrodes respond satisfactorily to the usual stress relief of 1 hr/in. of thickness at 1150° F as indicated by both tensile and impact tests. Table 6 gives the as-welded and stress-relieved tensile properties for welds deposited with $^{5}/_{16}$-in. diam electrodes. The tensile values for the as-welded condition were obtained on specimens that were held after machining for about 10 days before testing. They were, therefore, subjected to some natural aging which accounts for elongation values higher than those previously given for as-welded and unaged specimens.

Figure 17 gives the as-welded and stress-relieved Charpy V-notch impact values. If 15 ft-lb are taken as the minimum acceptable impact value, this figure corresponds to 0° F for the as-welded condition and −15° F for the stress-relieved condition.

In closing, a few comments on contact electrodes other than the rutile or E6024 are in order. Most of the welding industry's interest in contact electrodes has so far been focused on that type. It will continue to receive attention until such time as its economic possibilities are fully realized, but not at the expense of development and application on other types of contact electrodes.

The E6027 electrode has already received considerable attention and we can look forward to increased emphasis on applications where it offers potential savings for the fabricator. Another type, as yet unclassified by the AWS-ASTM Filler Metal Committee, is the low-hydrogen contact electrode. Both the E6027 and low-hydrogen contact electrodes possess excellent operating characteristics and deposit welds capable of meeting the most rigid requirements.

Contact electrodes, although still in their infancy, have shown a healthy growth and are beginning to occupy their rightful place in supplementing conventional electrodes to meet industry's needs.

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2. Roberts, Aubrey Thomas, and Paterson, John Hamilton, U. S. Pat. 2,009,240 of July 23, 1935.
3. Pintard, J., *L'Air Liquide*, Paris, France. Private communication.

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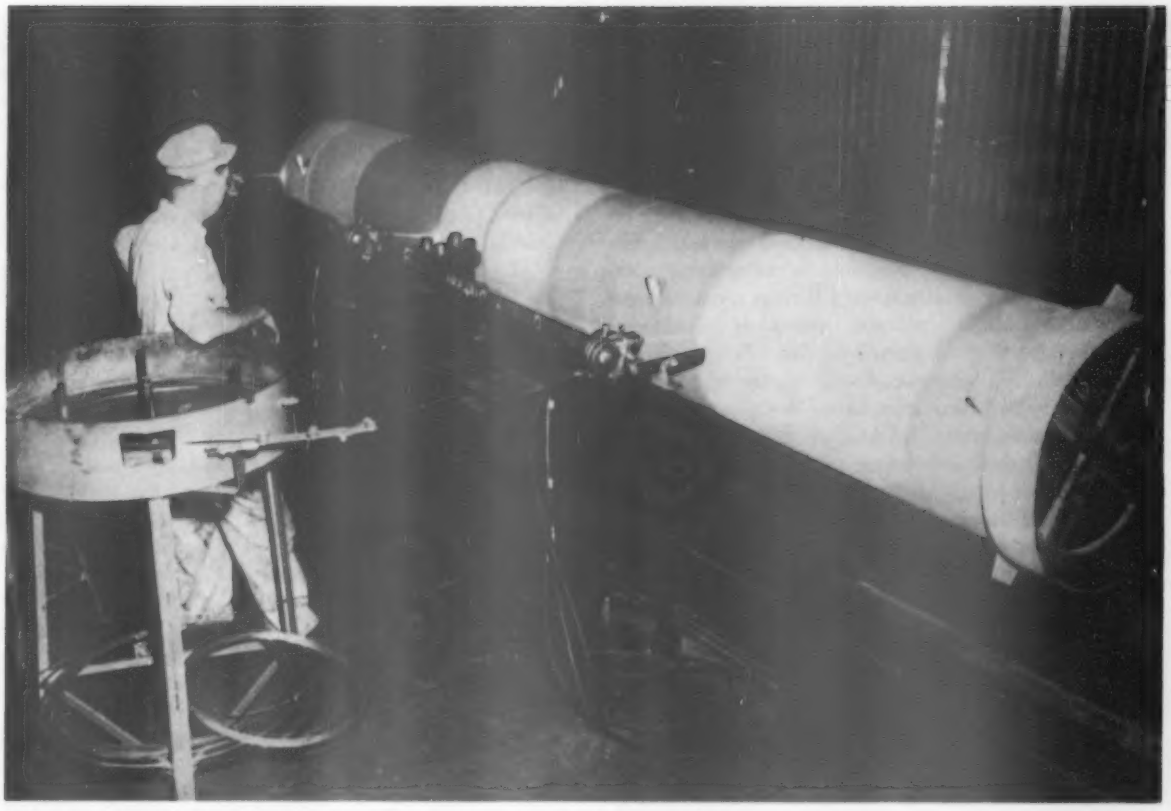

Refinery gasification tube being metallized for protection against heat corrosion.
(Courtesy of Metallizing Engineering Co., Inc.)

FUSED-IN-PLACE SPRAY METALLIZED COATINGS

Methods of metallizing and fusing, metallurgical nature and service applications are given for several fused-in-place spray metallized coatings

BY SAM TOUR

Introduction

A symposium on fused metallized coatings would be incomplete if it did not include the non-self-fluxing variety of metallic coatings fused in place. The development of the self-fluxing variety of hard and corrosion-resistant alloy coatings of the nickel-chromium-boron-silicon variety has been a great step in advance and recently has overshadowed the long-time use of fused metallized coatings of other metals.

What is a self-fluxing alloy as distinguished from a non-self-fluxing alloy? In order to obtain alloying of a coating as spray-metallized on steel by the melting of that coating in place, it is necessary that oxidation of the steel surface as well as of the sprayed metal be avoided during melting or else that a flux of some nature be

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present to dissolve away the iron oxides from the steel surface and the oxides within and upon the sprayed metal. If all oxides are removed from the interface between the molten sprayed metal and the steel, the molten metal has the opportunity to wet the surface of the steel and alloy with it. A self-fluxing alloy, therefore, is one which contains within itself the necessary fluxing agents to combine with and remove as slag the iron oxide films from the surface of the steel and a certain amount of the oxide inclusions in the sprayed metal itself. The boron and silicon alloying agents in the nickel-chromium-boron-silicon variety of hard surfacing metals are these fluxing agents. Since they are contained within the metal, the metal is therefore classed as a self-fluxing metal. Metals sprayed on steel and not containing materials that can act as a flux are obviously non-self-fluxing alloys or metals. In this category there are lead, tin, zinc, aluminum, copper, brass, Monel, Nichrome, stainless steel, nickel, etc. In the absence of oxygen or interfering oxide films on the surface of the steel, each of the metals just referred to will alloy with iron or steel when these metals are melted on the surface of the iron or steel.

One might jump to the conclusion that each of these metals could be sprayed on steel and then the product heated in a hydrogen atmosphere to above the melting point of the sprayed-on metal and thus create a fused-in-place layer of the additive metal on the steel. It is not quite so simple as it sounds. Hydrogen may prevent the formation of new oxide skins and may promote the wetting action of the molten surface layer on the steel. However, any oxygen present in the sprayed metal tends to form water vapor which in turn forms bubbles and blisters in the fused-on coating. The borate-silicate slag which forms from the boron and silicon constituents of the self-fluxing variety of hard surfacing alloys has a high dissolving power for iron oxides and other metal oxides and does not create a gas to cause bubbles and blisters. Mineral fluxes such as zinc chloride, boric acid, borax and rosin paste containing such mineral fluxes can be applied on top of a sprayed metal coating on steel and heat can be applied to fuse the sprayed metal coating in place under this flux blanket. Attempts to carry out this procedure show some of the difficulties involved. The flux layer melts and runs off of the surface or some of the residual fluxes of the chloride nature become entrapped in the fused-on layer and promote after-corrosion. The process is not so simple.

Steel surfaces are thoroughly cleaned and grit blasted before metallizing. In the "as metallized" condition, the steel surface itself can be considered as substantially free of oxide contamination. In the process of spraying the sprayed metal picks up a percentage of oxygen during its travel through the air from the tip of the spray gun to the surface upon which the spray is applied. The sprayed metal coatings, therefore, contain a percentage of oxides distributed throughout the sprayed metal. While these oxides within the sprayed metal do not interfere with the ability of the sprayed metal to wet the steel when it is fused in place, they do interfere with the fusing of the sprayed metal and they do make the molten sprayed metal sluggish as compared to a similar metal free of large quantities of metallic oxides. In some cases, the oxides within a film of molten metal will float or migrate to the surface of that metal and will allow the molten metal to alloy with the underlying steel upon which the sprayed metal coating has been applied. Acknowledging the difficulty introduced by metallic oxides contained in the sprayed metal coating, it becomes necessary to heat the sprayed metal to fusing temperature without the introduction of additional oxidation. Also, acknowledging that sprayed metal coatings are porous, it becomes necessary to prevent oxygen or air from passing through this porous layer to the surface of the steel and oxidizing the steel surface at the interface before the sprayed metal layer becomes fully molten and blankets the steel surface from further oxidation. Steel begins to oxidize at temperatures as low as 400° F as indicated by the temper colors which form on steel when heated in air. At temperatures as low as 400° F, the oxidation film is very thin and appears as a straw color. At higher temperatures, the film becomes thicker and the color becomes darker. At temperatures of 700–800° F, the oxide film formed on steel heated in the presence of oxygen or air becomes blue to black and of appreciable thickness. At temperatures above 800° F, a typical iron oxide scale will form on steel in the presence of oxygen Obviously, it is necessary to prevent the oxidation of the steel by the penetration of air or oxygen through the porous metallized layer during the heating-up period before the sprayed metal coating can become molten. It is obvious, therefore, that an alternative method to the application of a flux layer on top of the sprayed metal layer is the application of a sealer coat of a nature which will prevent the penetration of air or oxygen up to the melting point of the sprayed metal. One example of this is the use of a bitumastic paint as a seal coat on top of sprayed aluminum on steel. The bitumastic paint seals the pores or porosity in the sprayed aluminum layer and prevents oxidation of the base metal during the period that the surface is being heated up to and above the melting point of the aluminum. This type of sealer can be used equally well on the metals with melting points below that of aluminum such as lead, tin, zinc, etc. As an added protection and to increase the resistance of the bitumastic paint to oxidation and burning away, the bitumastic paint can be loaded with aluminum flake powder. The leafing action of aluminum flake in bitumastic paint is a decided aid in the protection which the paint can supply during the heating to the fusion point of the sprayed metal layer. By the judicious use of selected sprayed metals and selected seal coats on top of these sprayed metals, or, within limits, the use of reducing atmospheres, it is possible to fuse in place a number of metals as spray metallized on steel surfaces and create a continuous dense layer of fused-on alloy thoroughly bonded to the steel surfaces.

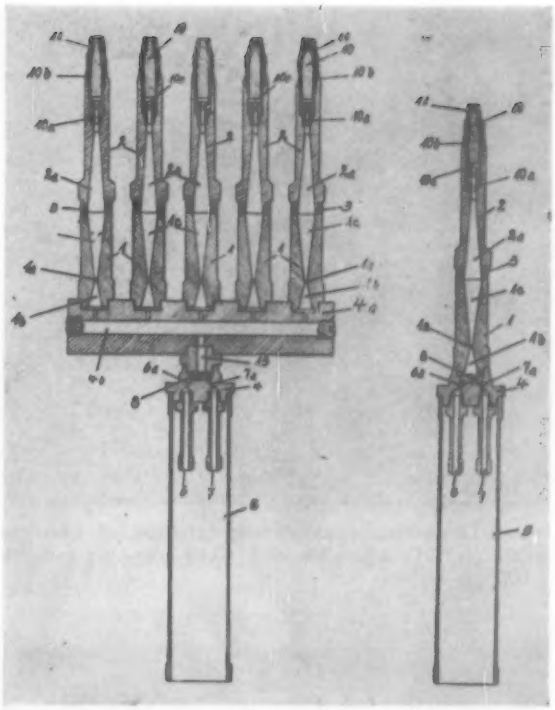


Fig. 1 Shoop's multiple-point burner as developed and published in 1919

History

The fusing in place of sprayed metal coatings is not new. The original inventor of the wire spray gun, M. U. Schoop, developed a special burner for this purpose over thirty-five years ago. Figure 1 is an illustration of his multiple point burner as developed and published in 1919. At the same time Mr. Schoop described wire gun metallizing with lead, with tin and with zinc, and subsequently, fusing these spray metallized coatings in place by the use of a heating torch or burner of this type. One of the early applications of spray metallizing was the use of sprayed aluminum coatings for the protection of iron and steel against oxidation and scaling at elevated temperatures. The aluminizing of steel for protection against oxidation and scaling was developed at about the same time that Mr. Schoop developed the wire spray gun. Aluminizing of steel for heat and scaling protection has been practiced ever since. Although there are numerous methods for applying an aluminum coating to the surface of iron or steel for the purpose of giving protection against oxidation and scaling at elevated temperatures, the spray metallizing method is the only one which will be discussed at this time. Spray metallizing with aluminum, using a wire gun, has been used in the United States to protect steel from oxidation and scaling continuously since 1921. In many cases, where the operating temperature in service is above the melting point of aluminum, the practice has been to simply spray the steel surface with a few thousandths of an inch of aluminum and then to introduce it into service use. In service use the aluminum melts, alloys with the steel and forms a fused-in-place coating. Aluminum has the unique property of combining with iron oxide and reducing it to iron-aluminum compound plus aluminum oxide. Aluminum oxide is inert and aluminum is able to carry a considerable percentage of aluminum oxide and still provide protection to steel. Iron alloyed with a few percent of aluminum or iron-aluminum compounds on the surface of iron afford excellent protection of the base metal against oxidation and scaling at elevated temperatures in the presence of free oxygen as in heating in air. To this extent, aluminum might be called somewhat of a self-fluxing alloy. When temperatures are high enough, aluminum will reduce any iron oxide present and molten aluminum will wet the steel surface so freed from iron oxide as a result of the reaction. Although thousands of thermocouple sleeves, annealing boxes, parts, etc. were sprayed with aluminum to provide heat and oxidation resistance during the 1920's and early 1930's, it was not until the late 1930's that the use of the bitumastic sealers, either with or without aluminum flake was developed and that this type of fused-in-place coatings became rather widely used. Since the late 1930's millions of dollars worth of annealing boxes, annealing covers, lead pots, salt pots, furnace and kiln parts, magnesium melting pots, damper plates, carburizing boxes and heat-treating pots, pyrometer tubes and brackets have been given heat and oxidation protection by fused-in-place sprayed aluminum coatings. This large use was the result of the development of the bitumastic coating containing aluminum flake as a seal coat on top of the sprayed aluminum.

In addition, the development of bitumastic seal coats made possible the use of sprayed chromium-nickel coatings and sprayed chromium-nickel alloy plus sprayed aluminum coatings for even greater protection against heat resistance. Sprayed aluminum coatings plus the sealer coat containing aluminum flake, as fused in place, are regularly used for temperatures up to 1600° F even in the presence of sulfur products in the surrounding atmosphere. Sprayed chromium-nickel alloy layers plus bitumastic seal coats containing aluminum flake have been used regularly in the temperature range from 1600–1800° F when no sulfur fumes were present. For this same temperature range, where sulfur fumes are present, a sprayed chromium-nickel alloy layer, plus a sprayed aluminum layer, plus the seal coat of bitumastic paint with aluminum flake, has been used for many years.

In spite of this history of the great success of providing oxidation and heat resistance to steel by the use of spray metallized aluminum or by the use of composite sprayed metal layers of nickel-chromium alloy plus aluminum, there has been little attention paid to the many other possible fused-in-place sprayed metal coatings.

Advantages

There are a number of advantages gained by the use

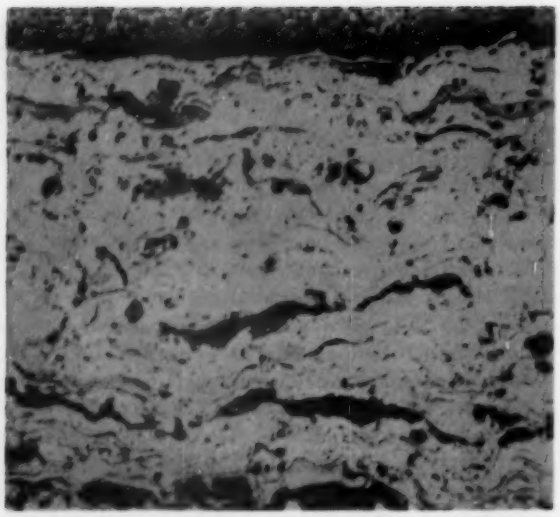


Fig. 2 Photomicrograph showing alternate layers of Ni-Cr-B-Si alloy and Ni-Mo-Fe alloy as sprayed X 100

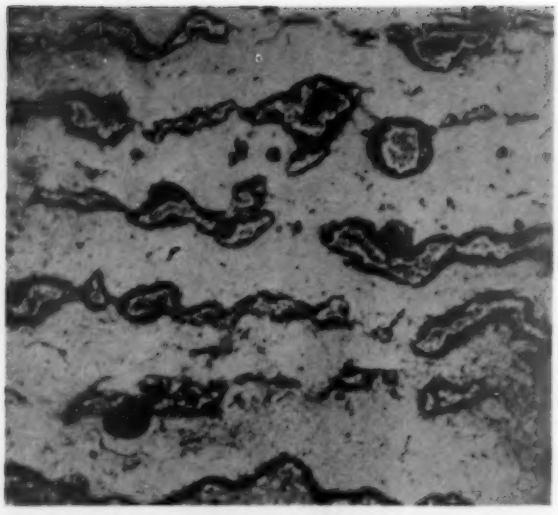


Fig. 4 Photomicrograph showing structure of alternate layers of Ni-Cr-B-Si alloy and Ni-Cr alloy as sprayed X 100

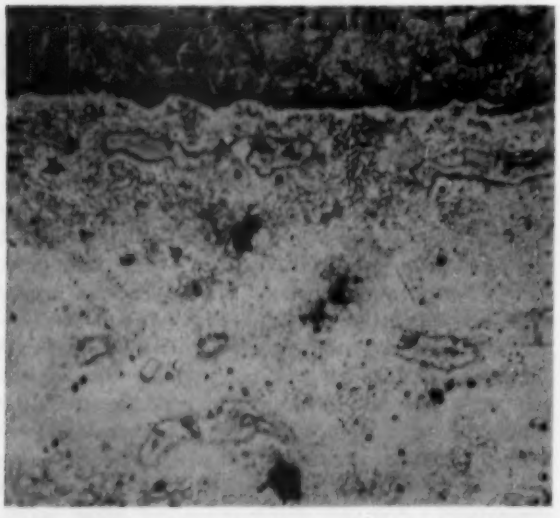


Fig. 3 Photomicrograph showing same materials as in Fig. 2 after fusing X 100

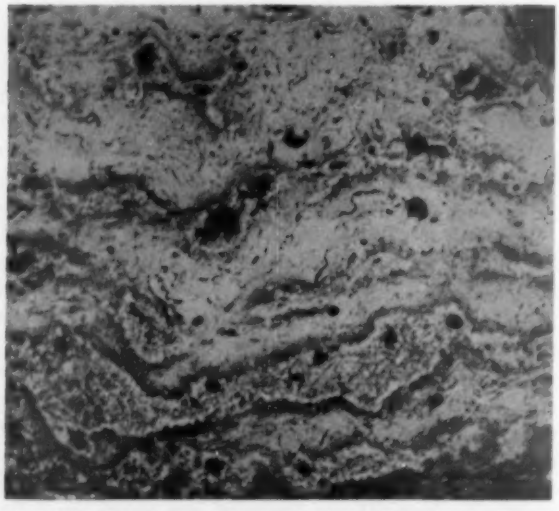


Fig. 5 Photomicrograph showing the materials in Fig. 4 after fusing X 100

of fused-in-place spray metallized coatings. Not least of these advantages is the adherence resulting from the alloying action of the fused coating with the base steel to create a bond which is completely free from peeling. A second advantage is the elimination of the natural porosity of the sprayed metal coating and, therefore, the complete sealing off of the base material which has been sprayed from the surrounding environment, whether it be gaseous or liquid in nature. Additional advantages have to do with the fact that it is possible to spray alternate or composite layers of different metals and, thus, create a desired alloy by the spray metallizing plus fusing process. It is a simple matter to operate two wire spray guns simultaneously and direct the two sprays to substantially the same area and thus create a spray metallized layer which is a composite of the metals coming from each of the two spray guns. By using the alternate layer technique, it is possible to vary the ratio of the two or more composite metals in any way desired. For example, if a composite equivalent to 80 and 20% respectively is desired, it is a simple matter to spray the two metals in this ratio in alternate thin layers and then fuse them in place. Similarly, if it is desired to impregnate an initial layer of one sprayed metal with a second metal of lower melting point, it is a simple matter to apply the desired layer of the first metal on the surface of the steel and then cover it by spraying on of the second metal. By

subsequent heating to a temperature above the melting point of the second metal, it can be caused to fuse and impregnate the first sprayed metal as applied to the surface in question. The alloy and composite possibilities obtainable by this method are without limit.

By this composite or alternate spraying method, it is a fairly simple matter to obtain fused composite coatings made by the fusing in place of alternate metallized layers of the self-fluxing type of nickel-chromium-boron-silicon alloy and such other metals as copper, nickel, Monel metal, stainless steel, Hastelloy, etc.

Examples—Fused Self-Fluxing Plus Non-Self-Fluxing Coatings

Following are a number of examples of fused spray metallized self-fluxing alloys and fused alternate layers of self-fluxing alloys and non-self-fluxing metals. Samples were prepared by spraying alternate layers of a Metcoweld H (nickel-chromium-boron-silicon alloy) self-fluxing alloy and other metals such as Metcoloy #33 (nickel-chromium alloys), Monel, and Hastelloy A (nickel-molybdenum-iron alloy). The $1^1/_4$ in. diam carbon steel bars were mounted in a lathe and were sprayed alternately with the previously mentioned materials. Then, a portion of each bar was fused at a temperature which was sufficiently high to melt the self-fluxing alloy. Photomicrographs at 100 × magnification were taken of the materials in the as-sprayed condition and after fusing. The etchant used consisted of 7 parts HNO_3; 2 parts HCl plus $CuCl_2$ in excess.

Figure 2 is a photomicrograph showing alternate layers of the Ni-Cr-B-Si alloy plus the Ni-Mo-Fe-alloy as sprayed. The layer formation is evident.

Figure 3 shows the same material after fusing. It will be noted that considerable diffusion has occurred between the layers so as to form almost a single composite alloy layer on top of the steel.

Figure 4 shows the structure of alternate layers of Ni-Cr-B-Si alloy and Ni-Cr alloy as sprayed. The layers are defined rather sharply.

As illustrated in Fig. 5, a considerable amount of diffusion is evident between the various layers after fusing. A cored type of structure has been developed. The layer has not been held in the molten state for a long enough period of time to become of uniform composition.

Figure 6 shows the structure of alternate layers of Ni-Cr-B-Si alloy and Monel metal as sprayed. The spraying technique, in this case, was such as to form very thin alternate layers.

Figure 7 shows the structure after fusing. Considerable alloying has taken place. Coalescence has concentrated the fine porosity into a series of larger voids.

In all of these alternately sprayed materials, it is evident that, during heating, diffusion has occurred between the various layers of metals. There seems to be a slight increase in porosity in the fused versus the as-sprayed metal due to coalescence of the alloys during fusion. Oxide inclusions seem to have decreased due to the fluxing action of the self-fluxing alloy layers.

Examples—Fused Non-Self-Fluxing Coatings

Following are a number of examples of fused spray metallized non-self-fluxing alloys on steel. Low carbon steel panels, 4 x 6 x $^1/_8$ in. thick, were grit blasted and then sprayed. Specimens for metallographic ex-

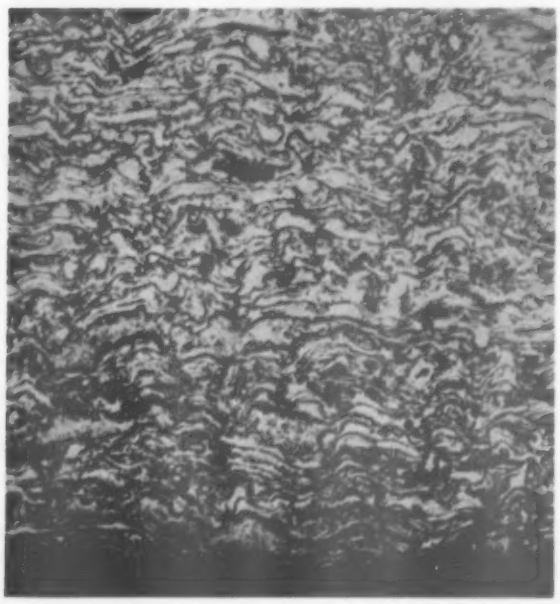


Fig. 6 Photomicrograph showing the structure of alternate layers of Ni-Cr-B-Si alloy and Monel metal as sprayed X 100

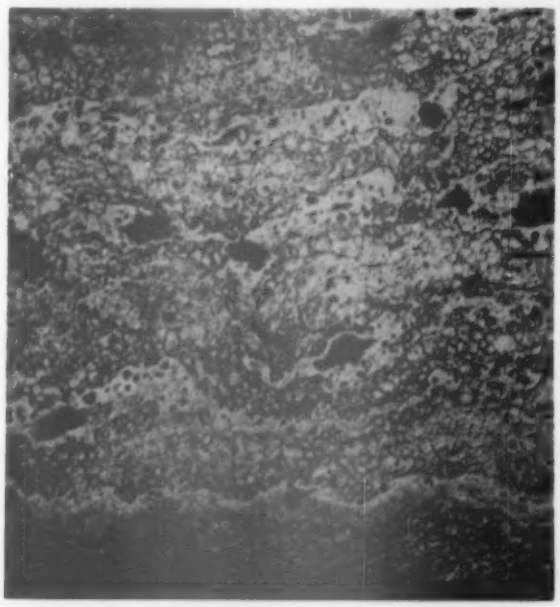


Fig. 7 Photomicrograph showing the structure of the materials in Fig. 6 after fusing X 100

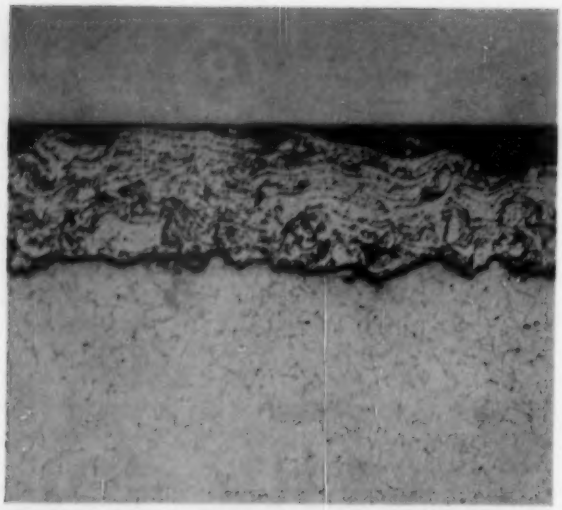


Fig. 8 Photomicrograph showing structure of 0.006 in. of aluminum as sprayed on steel X 100

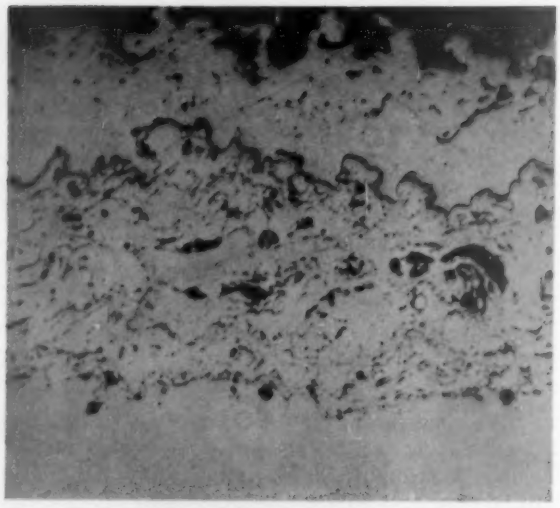


Fig. 10 Photomicrograph showing structure of 0.015-in. Ni-Cr alloy plus 0.006-in. Al as sprayed on steel X 100

Fig. 9 Photomicrograph showing iron aluminum compound structure formed on heating sample in Fig. 8 for 2 hr at 1500° F X 100

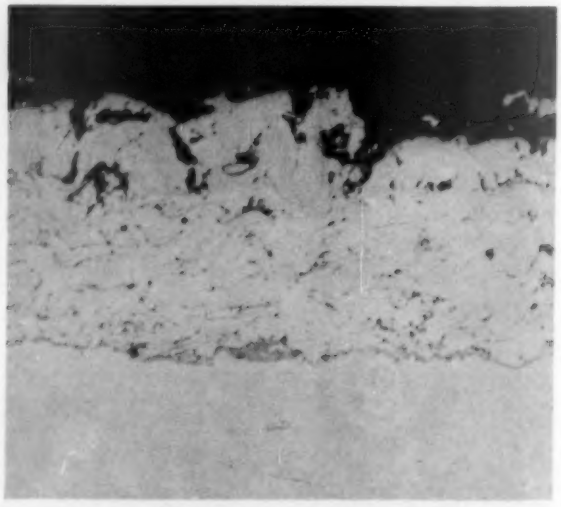


Fig. 11 Photomicrograph showing structure of the material in Fig. 10 after heating for $^1/_2$ hr at 1500° F X 100

Table 1

Metallized coatings	*Seal coat*	*As-sprayed, Figure No.*	*Fusion treatment Temp., ° F*	*Time, hr*	*As-fused, Figure No.*
0.006-in. Al	Yes	8	1500	2	9
0.015-in. Ni-Cr alloy + 0.006 in. Al	Yes	10	1500	$^1/_2$	11
0.006-in. Monel + 0.006 in. Al	Yes	12	1500	$^1/_2$	13
0.010 Type 310 Stainless + 0.006-in. Al	Yes	14	1500	2	15
0.006-in. Ni + 0.005-in. Zn	No	16	1000	1	17
0.006-in. Ni + 0.005-in. Sn	No	18	1000	1	19

amination were removed from each panel in the "as-sprayed" condition. Each panel was then heated to a temperature sufficient to cause fusion of at least some of the sprayed metal. Specimens for metallographic examination were removed from each panel in this "as-fused" condition.

Table 1 shows the various coatings applied, fusion treatments given and the figure numbers for the microstructures obtained.

The examples may be divided into three groups; first, aluminum alone; second, a high melting point metal plus aluminum; and third, sprayed nickel plus sprayed zinc or tin. A reducing atmosphere was used for all of the treatments.

Figure 8 shows the structure of the 0.006 in. of alu-

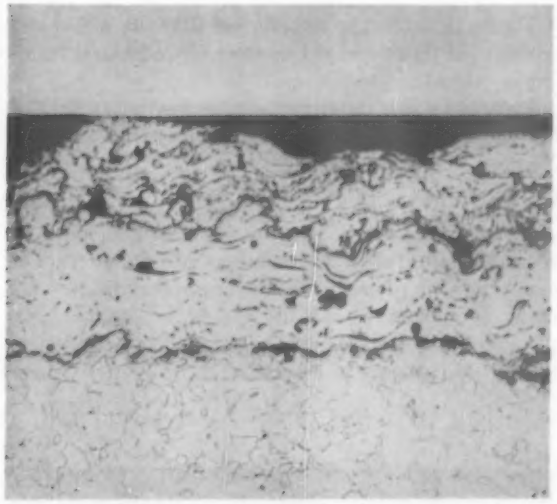


Fig. 12 Photomicrograph showing structure of 0.006-in. Monel plus 0.006-in. Al, as sprayed X 100

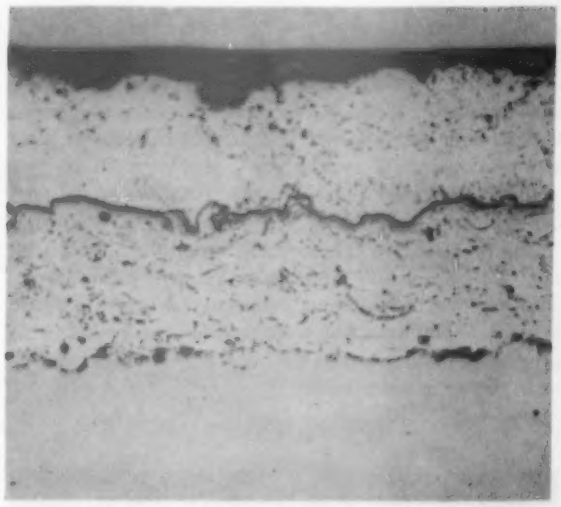


Fig. 14 Photomicrograph showing structure of 0.010-in. Type 310 stainless steel plus 0.006-in. Al, as sprayed X 100

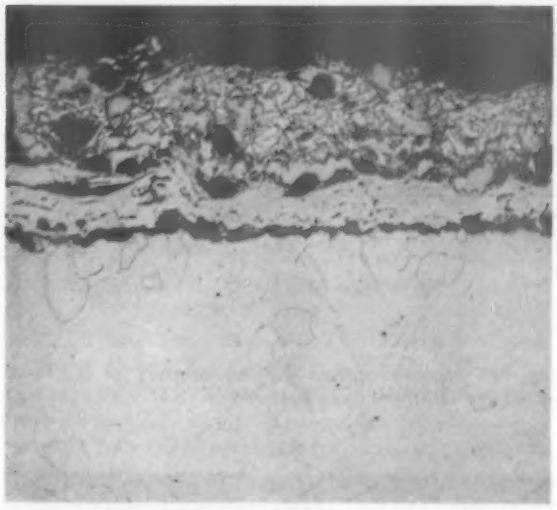


Fig. 13 Photomicrograph showing structure of material in Fig. 12 after heating to 1500° F for $^1/_2$ hr X 100

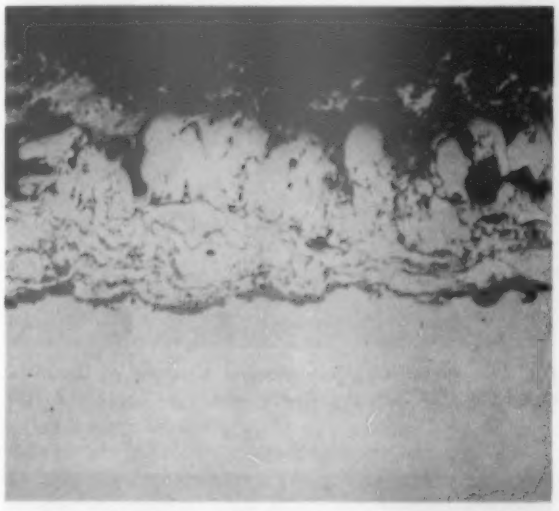


Fig. 15 Photomicrograph illustrating alloying and diffusion occurring between carbon steel, stainless steel and aluminum after 2 hr at 1500° F X 100

minum as sprayed on steel. The seal coat is not visible.

Figure 9 shows the iron aluminum compound structure formed on heating the previous sample for two hours at 1500° F.

Figure 10 shows the structure of 0.015-in. Ni-Cr alloy plus 0.006-in. Al as sprayed on steel.

Figure 11 shows the structure resulting from heating of the above for $^1/_2$ hour at 1500° F. It will be noted that diffusion between the aluminum and the Ni-Cr alloy and the steel has occurred. A thin alloy layer has formed between the steel and the Ni-Cr alloy.

Figure 12 shows the structure of 0.006-in. Monel +0.006-in. Al, as sprayed. The etched structure reveals the good but purely mechanical bond between the steel and Monel layer.

Figure 13 shows the structure of the above sample after heating to 1500° F for $^1/_2$ hour. The aluminum has melted and impregnated and alloyed with the Monel metal. Again, an alloy band has formed between the steel and sprayed metal. Voids are considerably exaggerated by repeated polishing and by the etching.

Figure 14 shows the structure of 0.010 in. of type 310 stainless plus 0.006-in. aluminum, as sprayed. Good mechanical bonding is shown.

Figure 15 illustrates alloying and diffusion occurring between the steel, stainless and aluminum after two hours at 1500° F. The grey band between the steel and first layer of metal is prevalent as with the previous sample after fusion treatment. This band of

alloy layer exists only in samples where either nickel, nickel-chromium alloy, Monel or type 310 stainless was sandwiched between aluminum and steel and then heat treated. It does not occur between aluminum and steel or when nickel is sandwiched between steel and zinc or tin.

Figure 16 shows the structure of 0.006-in. nickel plus 0.005-in. zinc as sprayed.

Figure 17 shows the resulting structure after fusing at 1000° F for one hour in a reducing atmosphere. The excellent alloy bond between the layers is quite evident. The zinc has impregnated the nickel. No grey alloy band between steel and spray metal is noted as in the previous samples.

Figure 18 shows the structure of 0.006-in. nickel and 0.005 in. of tin as sprayed on steel. Mechanical bonding is evident.

Figure 19 shows the structure after heating at 1000° F for one hour. It can be seen that diffusion has occurred. No grey alloy band is seen.

Conclusions

The alloying possibilities by the fusing in place of composite sprayed metal coatings are infinite. The adaptation of properly selected combinations for use under special service conditions has just begun. The possibilities are enormous, but considerable development work remains to be done.

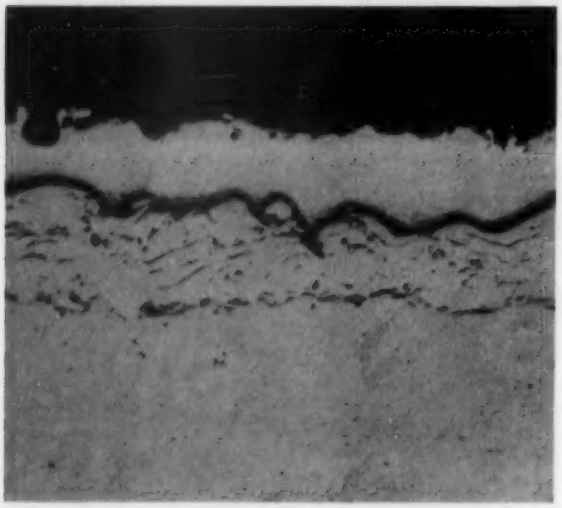


Fig. 16 Photomicrograph showing structure of 0.006-in. nickel plus 0.005-in. zinc, as sprayed X 100

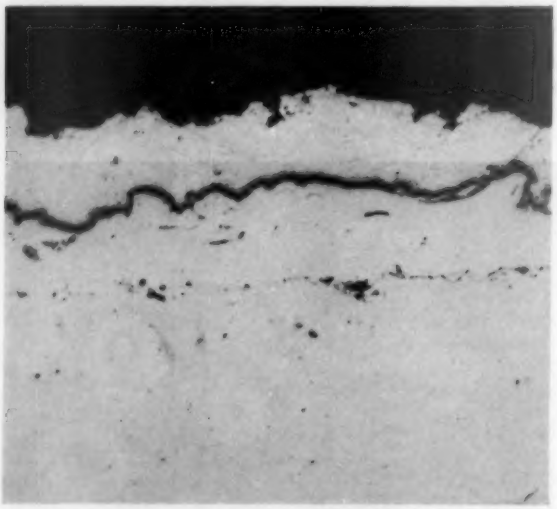


Fig. 18 Photomicrograph showing structure of 0.006-in. nickel and 0.005-in. tin as sprayed on steel X 100

Fig. 17 Photomicrograph showing resulting structure after heating sample in Fig. 16 at 1000° F for 1 hr in a reducing atmosphere X 100

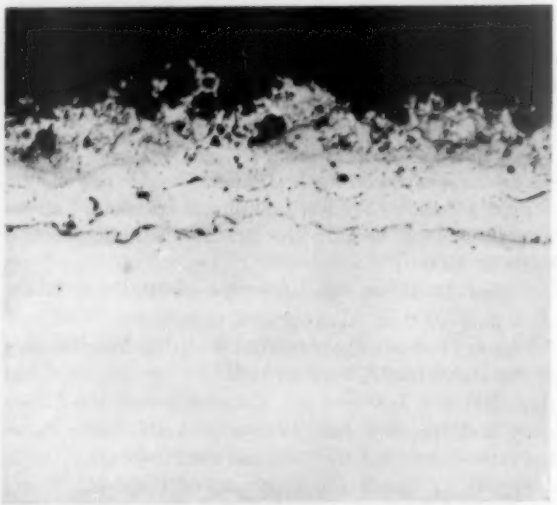


Fig. 19 Photomicrograph showing structure of material in Fig. 18 after heating at 1000° F for 1 hr X 100

AN IMPROVED METHOD OF OXY-FUEL COMBUSTION

Much higher heat release and higher gas velocity than have been used commercially heretofore, reported for improved type of oxy-fuel gas burner. New concepts of welding, cutting, flame hardening and descaling indicated

BY E. H. ROPER

Introduction

The superiority of the oxy-acetylene flame for purposes such as welding, oxygen cutting preheat, flame hardening, flame cleaning, and the like, is acknowledged by its widespread use for these purposes. However, acetylene has certain characteristics which have resulted in regulations limiting its pressure to 15 psig in apparatus such as currently used by the welding and cutting industry.

Thus, we find ourselves limited when we want to construct burners which require higher gas pressures in order to achieve the flows necessary to do more difficult jobs than can be done by acetylene when operating under the maximum pressure limitation of 15 psig.

Therefore, a research and development program was undertaken to develop burners that would use other fuel gases in the operating pressure ranges unavailable to acetylene. Such burners have been developed, and some knowledge as to their field of application has been accumulated. This paper proposes to summarize the work to date with a view to stimulating thought among engineers who might have uses for these heating principles.

Plan of Development

Neither the flame temperatures nor the heat content of a fuel gas are adequate yardsticks for measuring the ability of a flame to put heat into an object. Within recent years a concept known as "specific flame output" or "combustion intensity" has come into use as a means of comparing the heating ability of premixed gas flames.

E. H. Roper is Manager, Technical Market Development Section, Air Reduction Sales Co.

Presented at the AWS National Fall Meeting held in Chicago, Ill., Nov. 1–5, 1954.

This is generally expressed as:

$$J = \frac{V \times H}{K}$$

where

J = combustion intensity in Btu/sq ft of port area/sec
V = normal burning velocity in ft/sec
H = Btu per cu ft of the gas mixture under consideration
K = ratio of port area to area of inner cone

J is a maximum when the product of $V \times H$ is a maximum. H is large when the percentage of fuel in the mixture is large, but under these conditions V may be small.

For example, in the combustion of acetylene and oxygen the following is noted:

	Heating value, Btu/cu ft	*Burning velocity, fps*	*Combustion intensity (disregarding "K"), Btu/sq ft/sec*
Pure fuel	1433	..	..
Stoichiometric mixture ($2^1/_2$ to 1)	410	25.5	10,455
"Neutral" mixture, 1 to 1	716	17.5	12,530
40% mixture, 3 to 2	574	24	13,776

J will be a maximum when K is a minimum; hence, we want a flame with as long an inner cone as possible for a given port diameter.

This is the crux of the development. For, as we increase the pressure of the gas mixture in an effort to

force more gas through the hole of the tip, the inner cone will lengthen (giving a higher J) until the flame no longer burns back to the face of the tip. Thus, the problem becomes one of increasing the velocity at which the flame burns. This can be achieved by:

1. Keeping air away from the base of the flame. The air not only cools the flame, but the inert gases in the air dilute it.
2. Provide a better igniting source for the flame, or,
3. Add something to the flame that will increase the rate of combustion.

Skirting the orifice of the tip as shown in Fig. 1 keeps air away from the base of the flame, and the end of the skirt (which becomes quite hot) provides an ignition source. Commercially, skirting is often practiced as shown in Fig. 2 and permits much higher gas flows without reaching blowaway than is achieved with unskirted tips. The deeper the skirt, the more effective it is, but, as it becomes deeper, the end is affected by more of the flame and, if the skirt is deep enough, it will be destroyed. Also, devices can be put in the flame to interrupt the streamline flow, as in Fig. 3, but, if made large enough, they tend to fail as do skirts, and also they do not protect the base of the flame from the atmosphere.

If a series of small holes is placed around the flame and oxygen put through them so as to surround said flame, the quantity of gas mixture that can be burned in the central port without reaching blowaway can be greatly increased. In fact, if enough oxygen is blown through these holes, it may be impossible to reach the blowaway point. However, most of the oxygen will be dissipated in the atmosphere.

If we now introduce fuel gas with the oxygen, and thus surround the main flame with a ring of pilot flames we:

1. Protect the main flame from the air,
2. Add an ignition source, and,
3. Provide partial products of combustion, which increase the burning velocity of the main flame.

Obviously, these pilot flames will necessitate considerable complication of the tip construction, as shown in Fig.4, but Fig. 5 gives an idea as to what results can be achieved. Taking a conventional oxy-acetylene tip and a flame stabilized oxy-propane tip of the same port size, Fig. 5*a* shows the relative normal fuel gas pressures resulting in the normal gas flows of Fig. 5*b*, *c*, and *d*. As a result, we have the comparative energy releases of Fig. 5*e* with the flame stabilized burner releasing over four times the Btu output of the oxy-acetylene flame from the same size orifice. It would be interesting to know what might be achieved if a flame stabilized oxy-acetylene burner were operating under comparable conditions, but, since this would involve acetylene pressures higher than presently permitted in welding and cutting apparatus, it seemed pointless to carry out such studies at this time.

This flame stabilized oxy-propane flame has many interesting characteristics. As Fig. 5*f* shows, it has wide ranges of stable operation. Since it has high heat release and unburned gas velocities in the supersonic range,

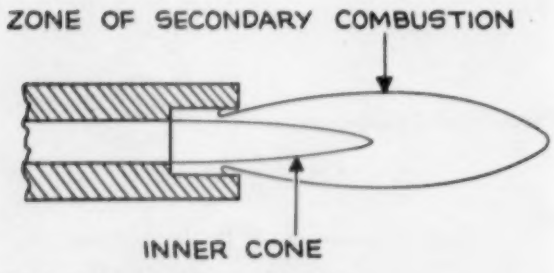


Fig. 1 Basic diagram of a skirted tip

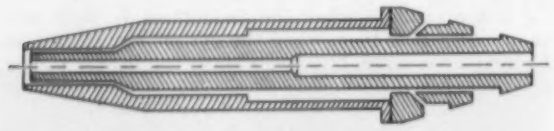


Fig. 2 Commercial application of the skirting principle

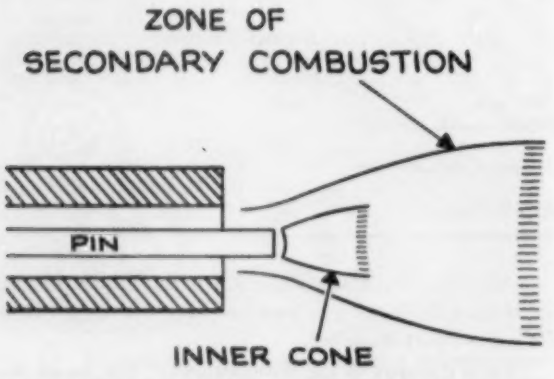


Fig. 3 Basic diagram of a flame interrupting device

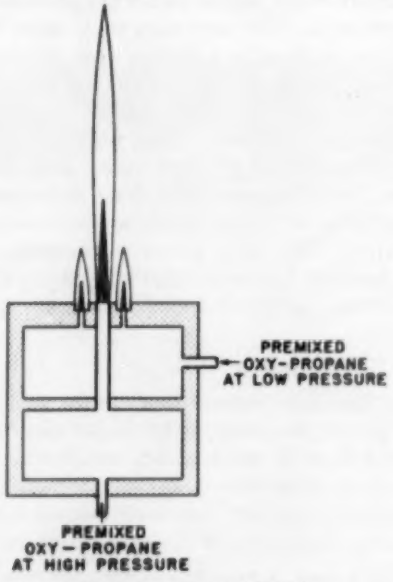


Fig. 4 Basic flame stabilized burner design

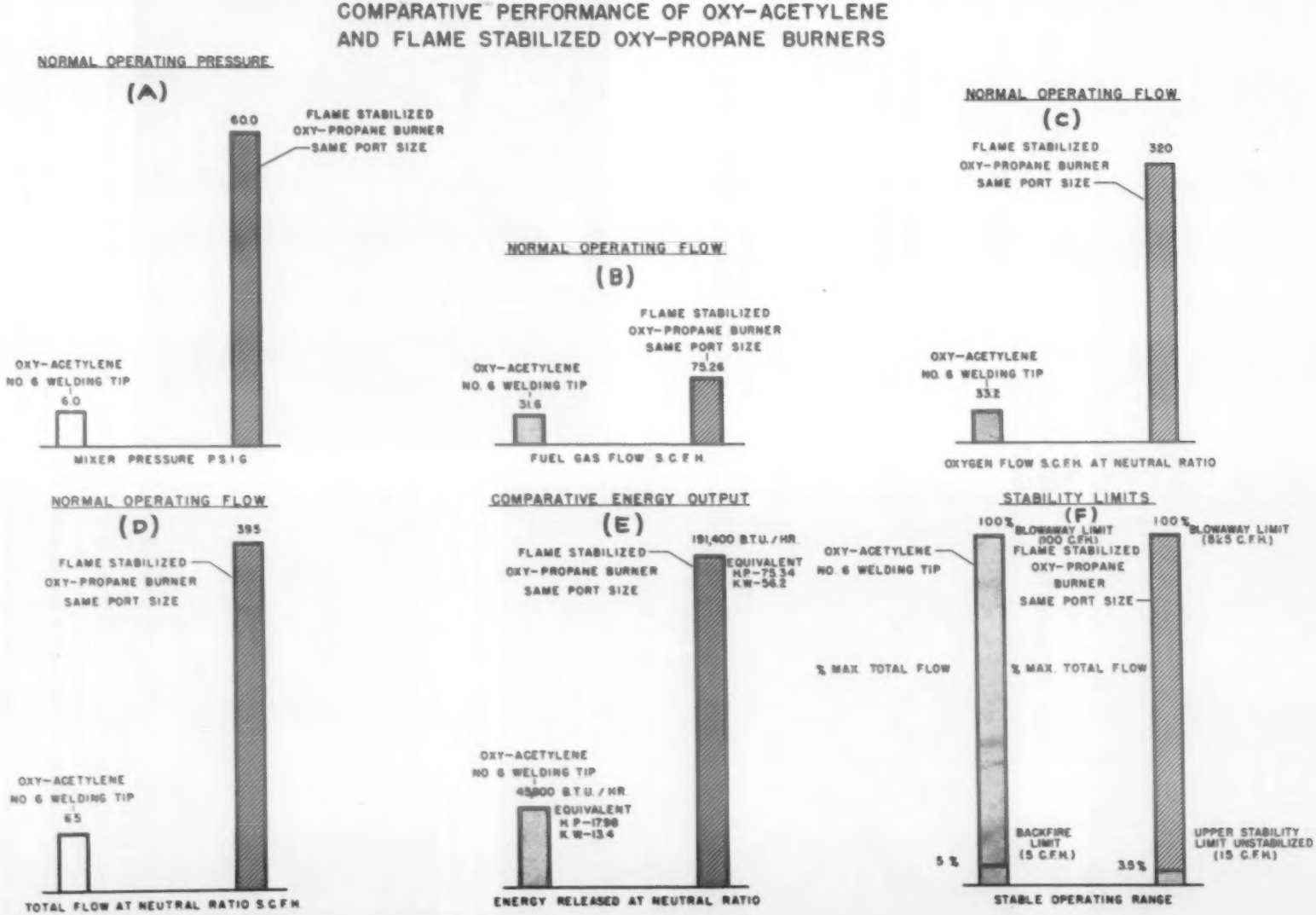


Fig. 5 Comparative performance of oxy-acetylene and flame stabilized oxy-propane burners

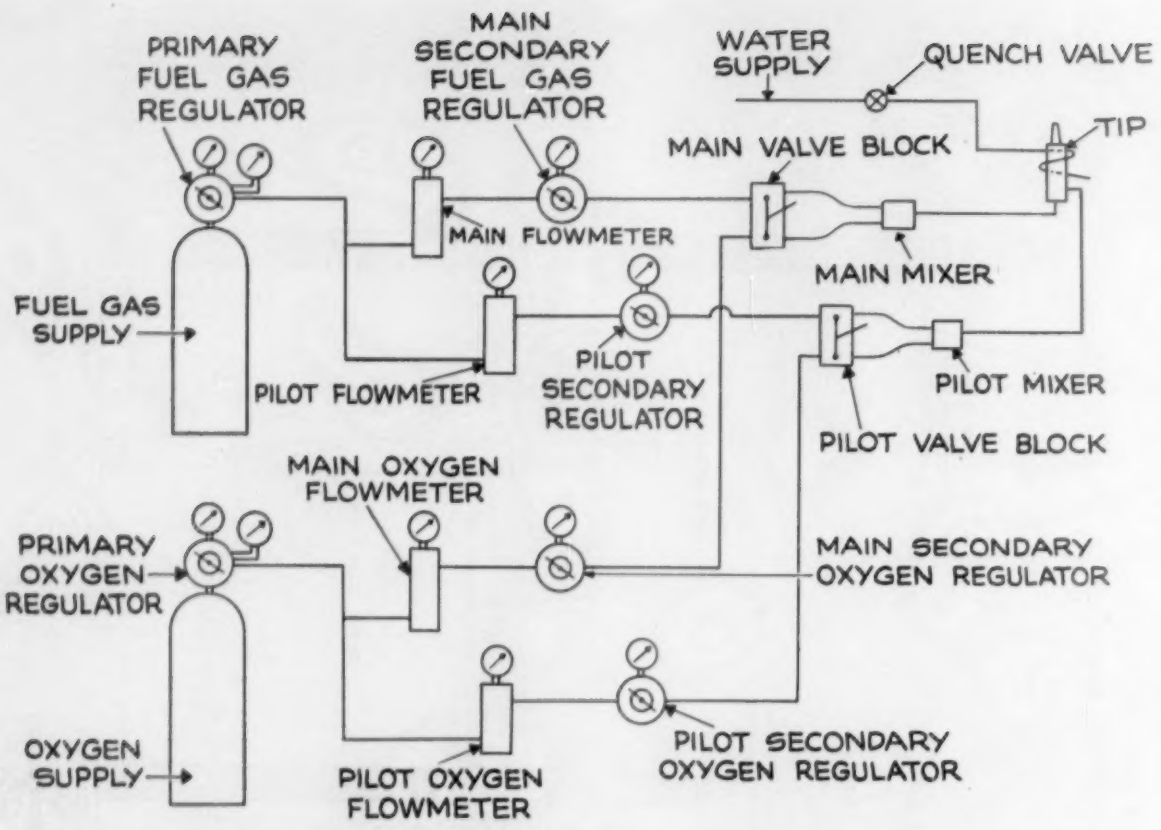


Fig. 6 Flowsheet of gas supply system for a flame stabilized burner

it has great ability to transfer heat to the work. This high gas velocity is not an unmixed blessing, since it bars the flame from welding operations. The impact of the flame is enough to blow metal away as soon as it softens.

Since two gas systems are involved with necessity to regulate them in relation to each other, the gas supply system is schematically shown in Fig. 6. These controls can be centralized on a panel as in Fig. 7. For portable operations the control panel can be eliminated.

The type of flame that can be achieved is illustrated in Figs. 8, 9 and 10.

The flame of Fig. 8 is from a $^{3}/_{16}$-in. diameter main orifice surrounded by eight pilot flames. Oxygen and methane are being burned with a total methane flow of 421 scfh and a total oxygen flow of 1070 scfh. Note the length of the inner cone. The pilot flames account for less than 2% of the total flow.

In Fig. 9 we have a flame consisting entirely of an inner cone and practically no secondary combustion, being operated under the highly oxidizing conditions of 37 scfh methane and 193 scfh of oxygen. Although the orifice is only $^{1}/_{16}$-in. in diameter, the inner cone is almost $1^{1}/_{2}$ in. long. Note how in these burners the pilot flames so blend into the main flame as to be almost indistinguishable.

Figure 10 represents a tip approximately a foot long with a row of pilot flame holes on either side of the center row of main flame holes. Clearly visible are the inner cones of the 211 main flames. This tip is burning a total of 520 scfh of propane and 2090 scfh of oxygen.

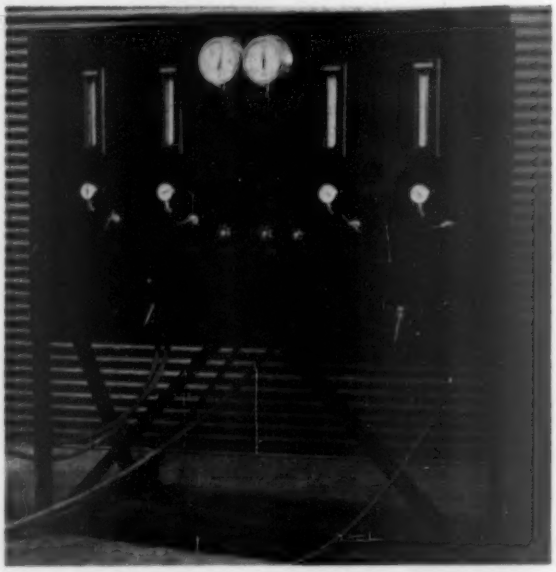


Fig. 7 Control panel for a large flame stabilized burner

Applications

A number of applications have been explored with in-

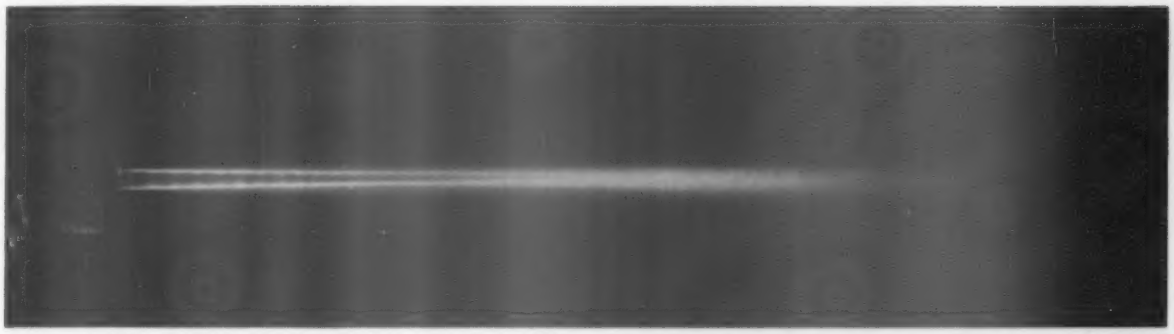


Fig. 8 Tip with $^{3}/_{16}$-in. diam main flame

teresting results. They will be described in sufficient detail to enable engineers who might have similar jobs to evaluate the possibilities.

Flame Cleaning

Successful flame cleaning requires a differential heating of the scale and base metal. Thus, the high temperature, high heat release, and great gas velocity of the flame stabilized burners would appear to have applications. Mechanized flame cleaning using a burner similar to Fig. 10 was tried on $^{3}/_{8}$-in. hot rolled mild steel plates that had not been subjected to any weathering. Experimentation with both oxy-acetylene and flame stabilized oxy-propane burners adjusted to produce what seemed to be the optimum results with each showed the following results:

	Flame stabilized oxy-propane	*Normal oxy-acetylene*
Tip speed, ft/min	10	5
Fuel gas per sq ft of surface cleaned, cu ft	0.73	0.75
Oxygen per sq ft of surface cleaned, cu ft	3.3	0.80
Estimated % of scale removed	30	15

Two passes of each tip were used in each case.

A portable flame cleaning torch and burner were constructed (Figs. 11 and 12) for manual operation. Only limited trials of this have been conducted to date using flows of 120 scfh for propane and 600 scfh for oxygen. The apparatus does a good flame cleaning job, but in its present state of development (which involves water cooling) is cumbersome. The operating gas pressures are in the order of 70 psig for propane and 90 psig for oxygen, which is more than is generally available from shop pipelines.

Our conclusions to date as regards flame cleaning can be summarized as:

1. The flame stabilized oxy-propane burner is approximately twice as fast as the unstabilized oxy-acetylene burner.
2. It is also approximately twice as effective in removing mill scale.
3. It uses approximately four times as much oxygen per unit of area cleaned.

Fig. 9 Tip with $^{1}/_{16}$-in. diam main flame

Fig. 10 Multiple-flame stabilized tip

4. It cannot remove all mill scale (nor can any flame process).
5. It is easier moved mechanically relative to the work.
6. The cost of operation as compared to the oxy-

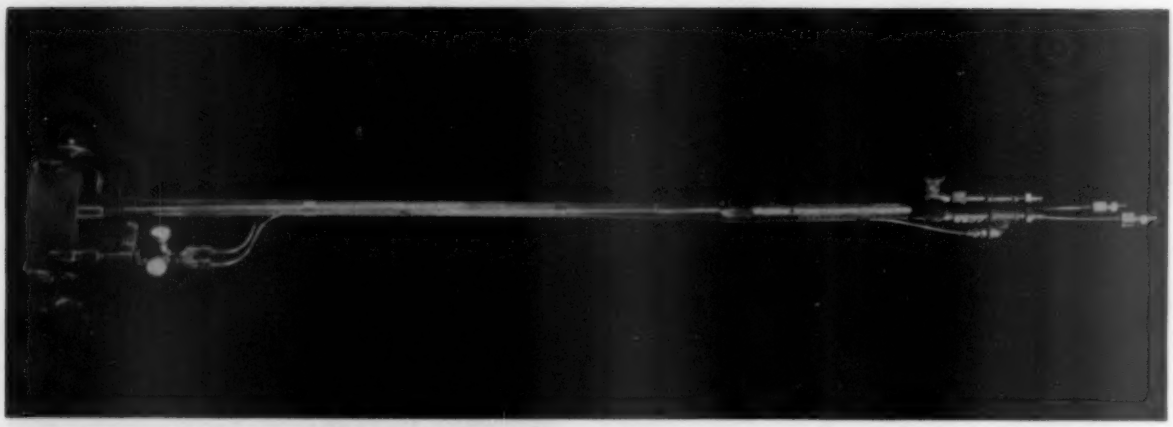


Fig. 11 Over-all view of torch and burner for manual flame cleaning

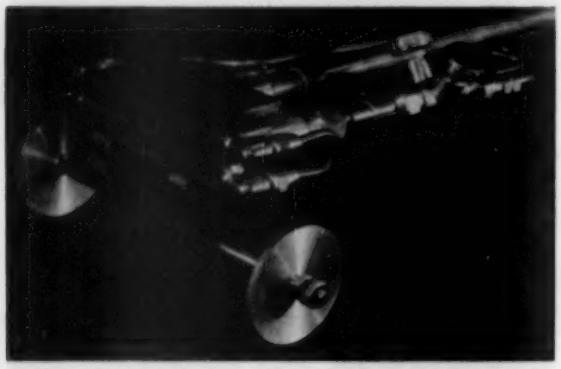


Fig. 12 Closeup of burner for manual flame cleaning

Fig. 13 Cross section of flame hardened specimen

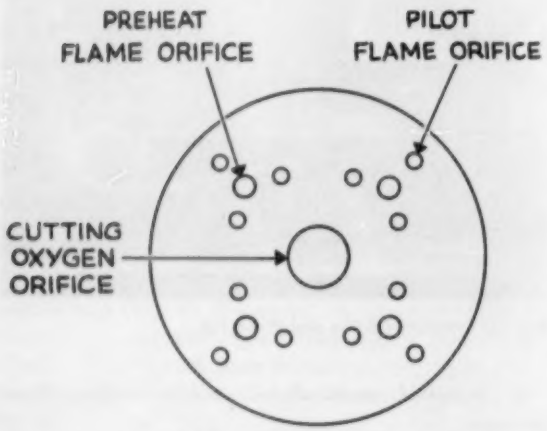


Fig. 14 Schematic diagram showing arrangement of orifices of flame-stabilized cutting tip

acetylene burner is too dependent on relative rates for labor, overhead, oxygen, acetylene and propane to permit drawing any general conclusions.

Flame Hardening

The flame hardening process generally depends on both an internal and an external quench. Hence, it is necessary that the area to be hardened be raised rapidly above its critical temperature so that the mass of material in the piece will still be relatively cool at the time heating is discontinued. While there exist a number of commercial flame hardening operations wherein the heat is supplied by oxy-propane or oxy-natural gas burners, it has generally been found that the use of oxy-acetylene flames is required in order to create the required differential heating of the workpiece. Once the flame stabilized oxy-propane burner was developed, it was natural to test it for flame hardening purposes. Several interesting possibilities and limitations were uncovered.

While oxy-acetylene flame hardening operations are conducted under a wide variety of operating conditions, a speed range of from 3 to 6 ipm producing a hardened zone from $^1/_8$ to $^1/_{16}$ in. deep, the flame stabilized oxy-propane burner seems better adapted to those applications requiring $^1/_{16}$ in. depth of hardness or less. Attempts to get a deeper hardened zone show results no better than achieved using oxy-acetylene burners. However, if the application is one for which a relatively thin hardened zone is satisfactory, then the flame stabilized oxy-propane burner offers possibilities because greater speeds are achieved. In Fig. 13 is shown a cross section of a piece 3 in. wide, $^9/_{16}$ in. thick, of SAE 1045 steel hardened with the following results:

Tip speed, ipm	23
Oxygen flow, scfh	1400
Propane flow, scfh	375
Depth of fully hardened zone, in.	0.035
Depth of transition zone, in.	0.039
Average hardness (Rockwell C)	
Fully hardened zone	65.5
Transition zone	50.5

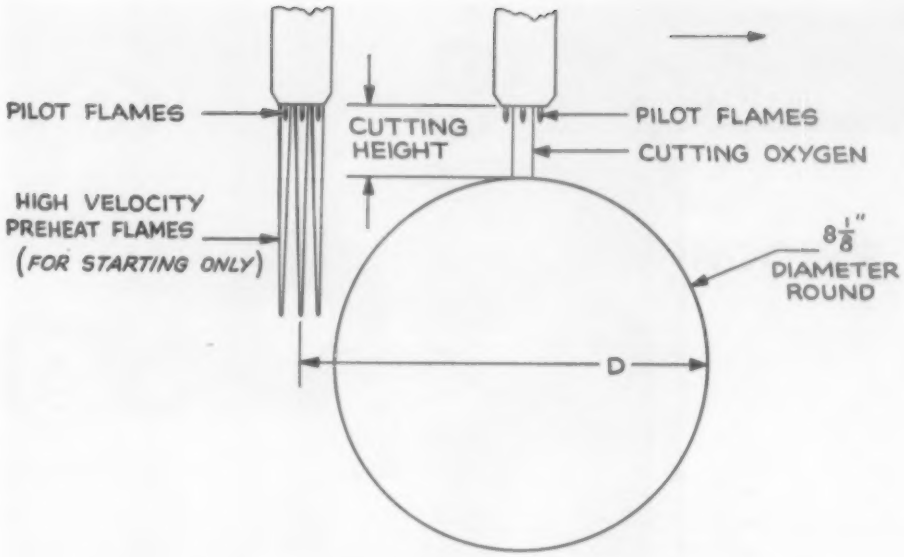


Fig. 15 Operating sequence for cutting $8^1/_8$-in. round

Most interesting is the speed, which opens new fields for the flame hardening process in the treating of machine parts needing a relatively thin hardened case, yet whose production rate is too low to justify an induction hardening setup and whose value is too low to justify flame hardening by the oxy-acetylene method.

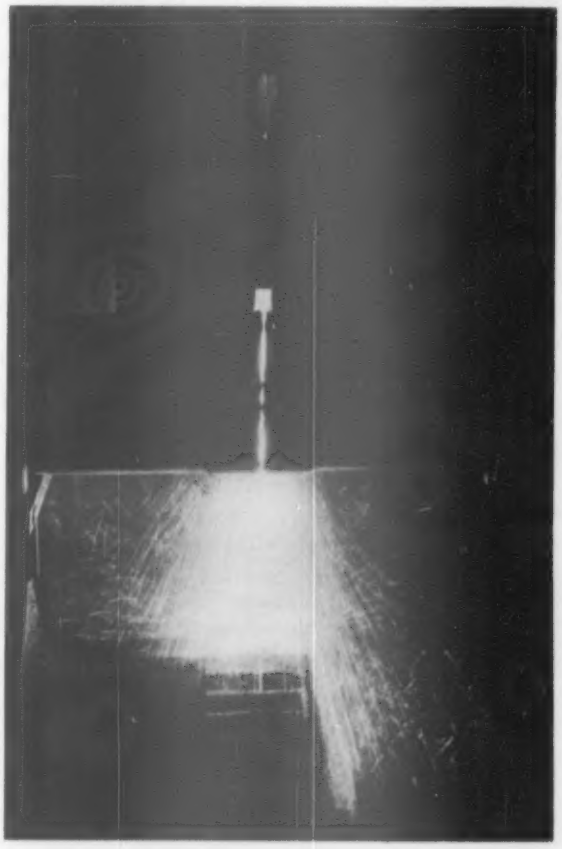
Preheat for Oxygen Cutting

In the oxygen cutting of rounds, a large part of the cutting cycle is the time necessary to initiate the cut. Unless the torch is moved in an involved path, the preheat flames at the start of the cut must operate at a distance and at a very unfavorable angle to the work. If very high preheats are used to start the cut, there will be melting down of the top edge at the midpoint of the round, unless the torch is raised or the preheat lowered. Since a cutting tip using flame stabilized preheat flames can be operated using just the pilot flames for preheat, a tip with a face as in Fig. 14 was used to cut mild steel rounds of $8^1/_8$ in. diameter. The tip and torch operated at a constant height and were moved into and across the work at 14 ipm. As shown in Fig. 15, the preheat flames were shut off after the "flying start" was made. As a result, the top edges suffered little rolling over, see Fig. 16. Data on this application are:

Size of round $8^1/_8$ in.
Temperature at start of cut 1650° F
Speed of starting and cutting 14 ipm
Total time 37.5 sec
Pilot flames
  On for 37.5 sec
  Propane flow, 40 scfh
  Oxygen flow, 200 scfh
Main preheat flames
  Propane flow, 200 scfh
  Oxygen flow, 400 scfh
Cutting oxygen
  On for 34.8 sec.
  Oxygen flow, 1900 scfh

In order to establish a control, cuts were made during the same series of experiments with the recommended standard oxy-acetylene cutting tip using 300 scfh acetylene and 330 scfh oxygen for preheat and a cutting oxy-

Fig. 16 View into midpoint of cutting operation on $8^1/_8$-in. round



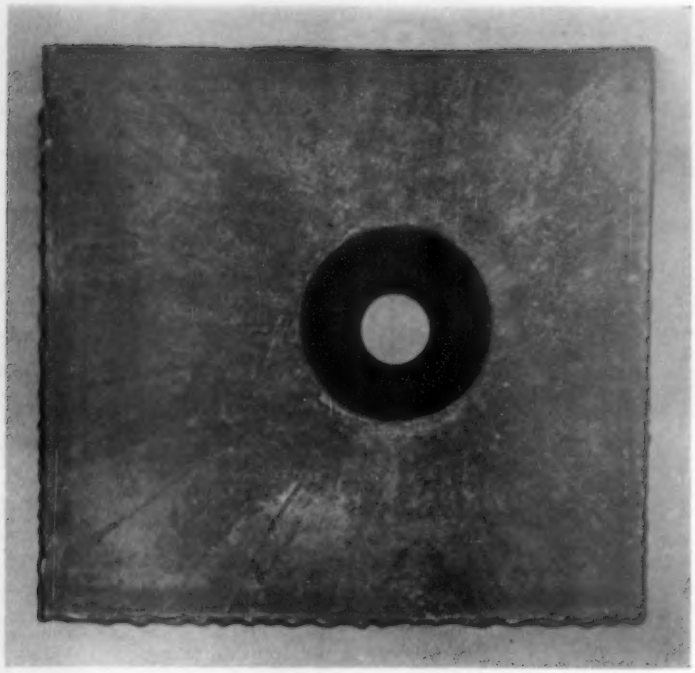


Fig. 17 Hole pierced by flame-stabilized flame

gen flow of 3100 scfh. Cutting speed was 21 ipm with a preheat time of 10 sec. and 25 sec. actual cutting time, giving roughly the same total time for making a cut. Whether a commercial application for hot cutting of rounds should employ flame stabilized oxy-propane preheat or normal oxy-acetylene preheat would depend on an analysis of the individual situation.

Glass Working

In general, glass working operations wherein a flame is employed call for a soft flame of relatively low velocity. Considerable work had been done using the flame stabilized oxy-propane and oxy-natural gas burners for piercing and cutoff operations in the glass industry. The work to date is inconclusive in that, while these burners will provide much more rapid piercing and cutoff than achieved heretofore, the very velocity of the flames may develop glass "strings" rather than a smooth cut. This work is still going on.

Piercing

Figure 17 shows a hole pierced in a mild steel plate $1^1/_2$ in. thick in 12 seconds. The plate, at room temperature, was placed horizontally one foot above a vertical flame stabilized tip with a main flame $^3/_{16}$ in. in diameter and six pilot flame holes around it. Total gas flow was 900 scfh of methane and 2700 scfh of oxygen. The smooth uniform conical hole is $1^5/_{16}$ in. in diameter at the front and $^1/_2$ in. in diameter in the rear. No commercial use for this operation has yet been found, but it is mentioned to show the power and possibilities of these flames.

Tube Welding

One of the major items of expense in the operation of an oxy-acetylene tube welder is the acetylene. The over-all economy of the tube welding operation can be substantially increased by using lower cost fuel gases to raise the edges of the skelp toward the welding temperature and then using the oxy-acetylene process merely to perform the actual welding operation.

Flame stabilized oxy-natural gas preheating has been experimentally tried for tube welding purposes. Considerably higher than usual speeds are possible taking into account, however, that the operation of a tube mill at increased speeds involves problems of forming, straightening, and cutoff, which are not directly connected with the welding operation.

Other Possible Applications

Using the burner of Fig. 10 strip steel stock 0.010 in. thick has been edge heated to a temperature of 2150° F at speeds up to 275 fpm. This would indicate possible uses for such burners for strip annealing or for forge welding. Certain machining operations might be performed hot after the surface of the workpiece had been raised to a softening temperature. We do not pretend to have thought of or investigated all possible applications, but some of the work done to date has been presented in this paper with the thought that it will stimulate thinking among engineers who have problems that these flames might solve.

Acknowledgment

The author wishes to thank the research and field technical staffs of the Air Reduction Company who developed these burners and conducted the experimental work described in this paper.

INERT ARC WELDING OF ALUMINUM CHURCH WINDOWS

Aluminum windows of unusual design and beauty standardized by special sections plus consumable-electrode inert-gas metal-arc welding

BY H. B. VAN FOSSEN AND J. HOLMSTOCK

Next time you see a beautiful Gothic window in a new church, a two-storied arched window in a new bank, a strikingly large expanse of window in a modern library building.. look a second time, it may very well be framed in aluminum!

For, these windows which must have both beauty and structural soundness can now be fabricated and assembled at reasonable cost into any style or size to meet architectural designs.

The story starts with Industrial Engineering Works, Trenton, N. J., creators of a unique design known as Twin-beam, who specialize in extruded aluminum sections for church windows, banks, libraries and government buildings.

IEW recognized that architects were handicapped by having to specify such windows as a special design. The cost of such custom-produced windows was often prohibitive; in many cases, forcing the acceptance of plain square-head windows. This often greatly lessened the architectural beauty of the building. IEW proceeded to tackle the problem of producing standard aluminum window sections which would meet architects' design and strength requirements.

This led to the development of the Twin-beam shape which results in a window of unusual beauty, amazing strength and stiffness in any size and, at the same time, provides perfect setting areas for double-glazed construction.

H. B. Van Fossen and **J. Holmstock** are associated with Air Reduction Sales Co., Philadelphia District.

Fig. 1 Gothic, circular, bull's-eye and wide variety of window frames assembled from standardized aluminum sections

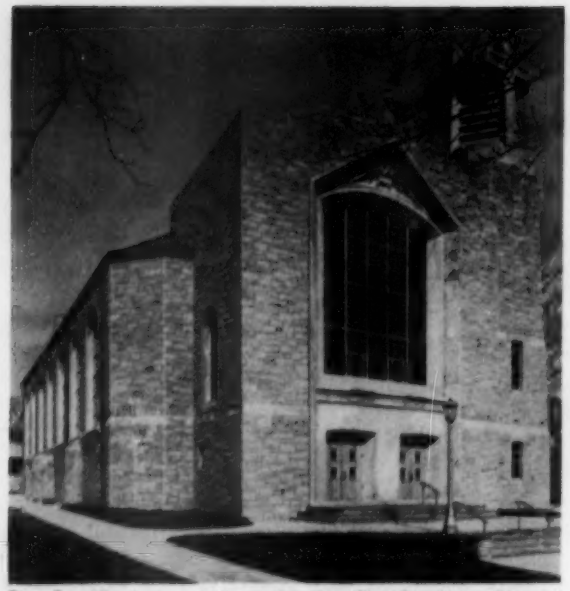


Fig. 2 Aluminum windows for the Church of the Blessed Sacrament, Trenton, N. J.

Fig. 3 Inert-gas welding process produces strong, completely sealed corner joints on aluminum window frame

With the aid of the adaptable consumable-electrode inert-gas metal-arc welding process, an integral part of this highly successful fabricating project, Industrial Engineering Works was able to standardize aluminum sections which can be readily assembled into Gothic, circular head, bull's-eye and many other style windows without costing appreciably more than standard square-head windows. This same fabricating process also makes it possible to produce outsize or unusual shape windows at far less than custom prices.

With this inert-arc welding process, moreover, they are able to produce strong, completely sealed corner joints displacing mechanical joints entirely. Structural strength is given in two directions by the Twin-beam design. Unusually large windows can be made without the use of stiffeners.

In addition, apart from the strength factor, these welded joints are watertight, an important consideration from the service standpoint of any window frame. Entire frames are fabricated as a unit and shipped complete, ready for installation. Without the welding process, connections would have to be mechanical and the frame shipped in separate parts.

Manual equipment is used for welding all joints in the frame and sash bars, and clamps hold the component parts during the operation. Wire feed speed is 175 ipm within an inert gas shield of 45 cfh argon. Amperage is set at 160.

An overhead travel crane assures ample clearance for the welding equipment and easy maneuverability from working point to working point. It travels 40 ft lengthwise and 15 to 18 ft sidewise, covering the area set aside for assembly and welding.

Joints are finished off to a smooth surface by rough grinding followed by polishing with steel wool, and this surface is then sprayed with a coat of lacquer. All visible surfaces of all the window frames which leave the Industrial Engineering Works plant are cleaned, polished and rubbed to satin finish.

Fig. 4 Close-up of inside corner weld

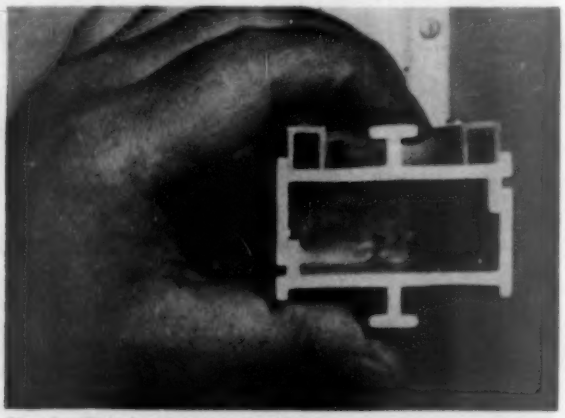


Fig. 5 Twin-beam cross section

Society News

Spring Meeting in Kansas City to Feature Many Special Events

In line with the AMERICAN WELDING SOCIETY'S policy to make the Spring Meeting and the concurrent Welding Show the outstanding activity of the year, many special events have been planned for Kansas City, June 7 to 10.

The recent change in the By-Laws which requires that the AWS annual meeting be held in the Spring is, of course, the principal factor in giving increased emphasis to the Spring Meeting. There are, however, many other special events of outstanding interest planned for the Kansas City sessions.

A keynote address by President Joseph H. Humberstone will officially open the Spring Meeting on Tuesday morning June 7th. President Humberstone will outline the objectives of the technical sessions and will describe the relationship of the papers to the needs of industry, the present trend toward automation and the benefits which will be derived by both the fabricator and the user of welded products.

The President's Reception will be held at a Spring Meeting for the first time. This event, the outstanding social occasion for the SOCIETY'S membership, will take place at the Hotel Muehlebach on Tuesday evening.

Immediately following the President's Reception, a banquet will take place and a speaker of national prominence will give the principal address.

At noon on Thursday, another "first" will take place. This will be a National Sustaining Member Luncheon to which leaders of the industry will be invited. Officers will discuss the year's achievements of the SOCIETY and will outline its plans and hopes for the future.

As a climax, on Thursday night, the Kansas City Section will play host to members at a giant barbeque. Kansas City, one of the world's great centers for choice steaks, is the logical place for an outdoor barbeque.

Advance indications of the scope of the Welding Show point to displays of equipment and accessories never before attained. The entire exhibit area laid out for the show was oversubscribed so quickly that it was found necessary to expand the space for exhibits. Even with the additional area, however, there is a likelihood that not all companies will be accommodated. It is a foregone conclusion that the third Welding Show will present the greatest assemblage of welding equipment and accessories ever gathered under one roof.

Some thirty-eight papers, covering all phases of welding and its uses, will be presented in 13 technical sessions. One of the highlights of the four-day meeting will be a symposium on the extremely important topic of welding qualification. This discussion will cover the basic principles, as well as the practical aspects of the qualifications of welders and welding procedures. Speakers will emphasize the relationship of qualification procedures to other factors involved in obtaining a satisfactory weldment.

Two sessions will be devoted to the important inert-arc welding methods. Applications where low-cost carbon dioxide gas has been used successfully as a shielding gas will be described. Other sessions will cover the use of welding in the fabrication of aircraft and rockets; welding of pressure vessels and piping; reducing maintenance costs by hard surfacing; welding and testing of structures; and resistance welding of molybdenum and titanium.

There will also be a paper on new self-fluxing brazing alloys, recently developed, which make use of small additions of lithium. Still another report will describe an efficient, high-quality flame brazing setup for fabricating electronic components. The performance of the new iron-powder electrodes and fusion welding of titanium are other topics covered.

Members who have not already done so are urged to make their hotel reservations promptly. The housing committee reports the greatest advance registration ever received for any Spring or Fall Meeting.

MUNICIPAL AUDITORIUM NEAR LEADING HOTELS

Kansas City's leading hotels are within three blocks of the auditorium. (A) Auditorium (1) Muehlebach (2) Aladdin (3) State (4) Phillips (5) Continental (6) President. The Pickwick is also a short distance away

Carrier Becomes Sustaining Member

Carrier Corp. of Syracuse, N. Y., the leading manufacturer, as well as the pioneer, of the rapidly expanding air conditioning industry, has become a Sustaining Member of the AMERICAN WELDING SOCIETY. The firm produces and distributes a full line of temperature and humidity control products, for industry, marine and home use. In addition, in large installations, Carrier employs construction people as a contractor.

Welding plays a vital role in Carrier manufacturing; practically every product incorporates the use of some type of welding. Their shops are equipped with the electric-arc, oxy-acetylene, inert-gas (all types) and resistance welding processes. Their people are skilled in welding of both ferrous and nonferrous metals in a range of thickness from 4 in. down to 20 gage, with complete facilities for heat treating, and laboratory testing including X-ray.

Carrier's main plants are located in Syracuse, N. Y., but the firm also has field shops in Long Island City, Philadelphia, Atlanta, Charlotte (N. C.), Los Angeles and Chicago, plus distribution centers throughout the nation.

Under a merger proposal now awaiting ratification by stockholders, Carrier operations would expand greatly. It is proposed that Affiliated Gas Equipment, Inc., national manufacturers of a full line of heating products, will become operating divisions of Carrier Corp. This would give the latter firm additional plants at Indianapolis; Tyler, Tex.; Monroria, Calif.; and Toronto, Canada.

Carrier's Sustaining (A) Member Representative is Harry E. Miller.

AWS Executive Meetings Go to Birmingham

Several years ago, there was instituted the policy of holding several meetings of the AWS Board of Directors each year in various AWS Section cities; this policy has been maintained whenever possible. Meetings have been held in a number of cities and, in each instance, local and nearby Section officers have been invited to join with the board members at one session of their meeting.

Soon after the institution of the new AWS Technical Council, it became evident that it would be beneficial to the Society and most convenient to the members of the Technical Council, Executive Committee and Board of Directors, if the timing of the meetings of these executive groups could be coordinated so that they could be convened at about the same time and in the same location.

On February 1, 2 and 3, the initial three day session of these organizations was held at Birmingham, Ala., in the Dinkler-Tutwiler Hotel. One day was given to each group, the Technical Council, the Executive Committee and the Board of Directors in the order mentioned. The results hoped for, and anticipated, were attained. At their respective meetings on Tuesday, February 2, and on Wednesday February 3, the Technical Council and the Executive Committee gave studied consideration to the items of their and the Board of Directors' agenda, ironed out many of the details which require much discussion, and then formulated conclusions which represented the overall thinking of all concerned. These items of business were then made ready for presentation to the Board of Directors at its meeting on Thursday, February 4.

As a result of these previous arrangements, the Board was able to transact, between 9:00 A.M. and 3:00 P.M. on Thursday, thirty-five items of business, twenty-six of which were on the Board agenda and eleven others brought to the Board through the Technical Council and by Board members under the item of new business. At other meetings, the same amount of business had required at least two and possibly three days.

Nineteen members of the Board of Directors, including the Society's officers, attended these activities. On Wednesday evening, the Birmingham AWS Section, under the leadership of E. R. Owens, *Chairman*, R. E. Clotfelter, *Secretary*, and A. E. Pearson, *District Director*, sponsored a very successful industry relations activity at Birmingham's beautiful Vestavia Country Club, on top of nearby Shade Mountain. Nearly eighty industrial leaders of the Birmingham area were invited to join with the Society's officers and Board members in a reception and dinner, thus affording each other the opportunity to become better acquainted and establishing even closer relationship between the Society and industry management.

Invitations extended to the officers of the Birmingham and nearby AWS Sections to join with the Board of Directors on Wednesday at their luncheon and closing session, were accepted by Fred Eckert, *Chairman*, and T. H. Shields, *Secretary*, of the Tri-Cities Section, E. R. Owens, *Chairman* of the Birmingham Section, and G. L. Tepley, *Past-Chairman* of the Chattanooga Section. Other Section officers sent regrets that, due to business activities, they could not attend.

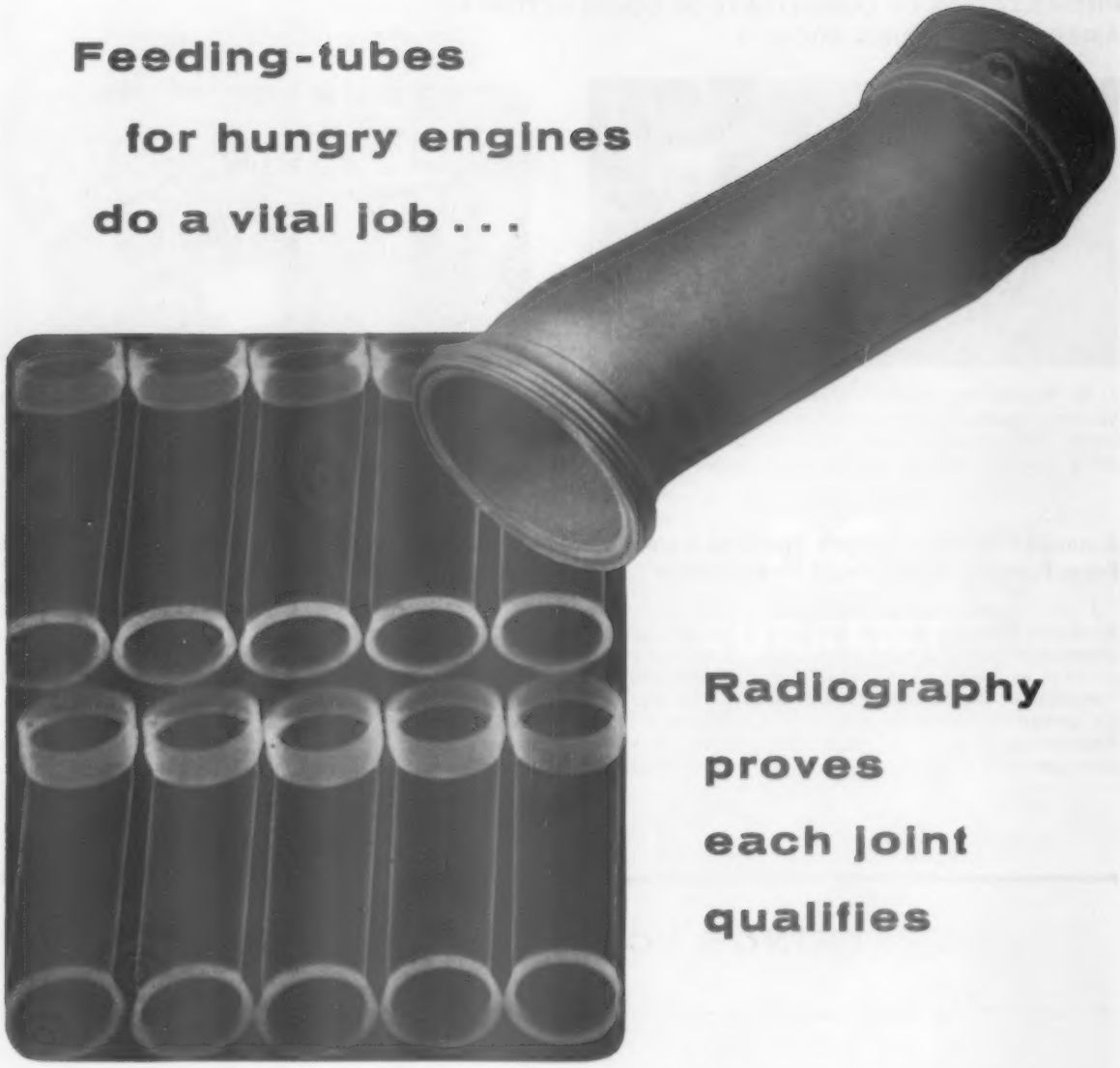
HIGHLIGHTS OF 3-DAY SESSIONS HELD BY SOCIETY LEADERS IN BIRMINGHAM

Just couldn't get all members of the Technical Council in this picture, but shown hard at work are AWS President J. H. Humberstone, Council Chairman "Is" Morrison, Member S. P. Sander and Guest C. E. Jackson

Birmingham industry representatives and AWS Board of Directors lost little time in getting fully acquainted at the reception held on Wednesday night at the Vestavia Club on Shade Mountain

At dinner on Wednesday night, following a fine talk by Mr. Whitney, member of Birmingham's Committee of One Hundred, President Humberstone told local industrialists what the Society means to industry at large

Feeding-tubes for hungry engines do a vital job . . .



Radiography proves each joint qualifies

GETTING the food and drink to the several thousand "metal horses" in a modern aircraft engine is no job to be taken lightly. Dependability is paramount. Safety a must. And lightness a prerequisite.

Joining these vital feed lines is a job for welding and brazing. And with radiography to prove each joint sound, there can be no dispute as to the acceptability of the work.

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PRESENTATION OF CERTIFICATE OF COOPERATION TO AMERICAN WELDING SOCIETY

J. H. Humberstone (center), president of the American Welding Society, receiving FOA award from D. F. Lane (right), vice-president of the National Foremen's Institute. Jon S. Jonsson, leader of Icelandic team, looks on

Mr. Humberstone, holding the award, flanked by members of the Icelandic team and representatives of the American Welding Society

American Welding Society Receives Award From Foreign Operations Administration

J. H. Humberstone, president of the AMERICAN WELDING SOCIETY and also president of Air Reduction Sales Co., accepted on behalf of the SOCIETY a Certificate of Cooperation awarded by the Foreign Operations Administration. Representing FOA, D. F. Lane, vice-president of the National Foremen's Institute, presented the certificate on Friday morning, February 25th, at the Engineering Societies Building, 33 W. 39th St., New York City.

The award, signed by Harold E. Stassen, Director of FOA, was given because of the significant contribution made by the AMERICAN WELDING SOCIETY in furnishing technical assistance to representatives of countries cooperating in the FOA program.

The Icelandic team, who have just completed an 11-week project of welding study in this country under the auspices of the FOA, was present at the ceremonies. The tour of this group, headed by Jon S. Jonsson of Iceland, was arranged by the National Foremen's Institute, Inc.

THINGS YOU SHOULD KNOW

Here are a few of the actions taken by the Technical Council at its meeting on February 1st in Birmingham, Ala., which should be of special interest to you. They will also give you an idea of how the newly organized Technical Council is functioning.

1. New Standards

A new Filler Metal Specification for Tungsten Electrodes and revised editions of the Chromium and Chromium-Nickel Electrodes and Mild Steel Electrodes Specifications were approved. The Mild Steel Specifications include new classifications for iron powder electrodes. All three specifications should be off the press shortly.

2. Welding Handbook

The Technical Council recommended that a new Staff man be employed to investigate preparation of a revised WELDING HANDBOOK.

3. Welding of Plastics

An investigation was organized to determine whether AWS should include the welding of plastics within its activities. (Comments or suggestions on this matter will be most welcome.)

4. American Council of IIW

The Technical Council took several actions to strengthen the participation of AWS in the American Council of the IIW and through it in the International Institute of Welding and the affiliated welding societies throughout the world. It recommended the appointment of the SOCIETY'S President as AWS representative on the American Council with the National Secretary as alternate. It recommended appointment of F. L. Plummer as AWS representative on IIW Governing Council. It also agreed to provide 30 copies of each new AWS standard, as issued, to IIW for distribution to IIW Communications on the basis of a mutual interchange of publications as available.

In the same connection, R. W. Clark and S. A. Greenberg were recommended as selections for the OEEC—Sponsored Tour of European Welding Operations. (Clarence E. Jackson has been selected by the Welding Research Council and the Ship Structure Committee for this same tour.)

5. AWS-AFS Committee on Welding Iron Castings

Organization of a Joint AWS-AFS Committee on Welding Iron Castings was approved. This Committee will be concerned with iron castings of gray iron, malleable iron and nodular iron which are to be welded in the course of fabrication, reclamation or repair. The membership is now being completed and the Committee should commence activities in a few months.

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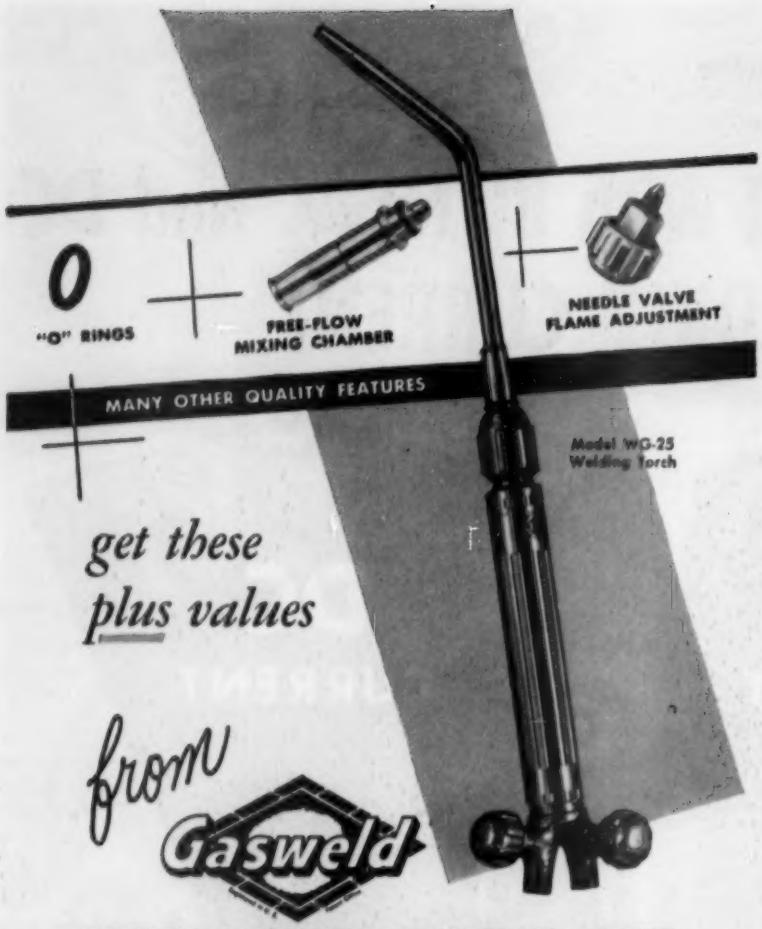

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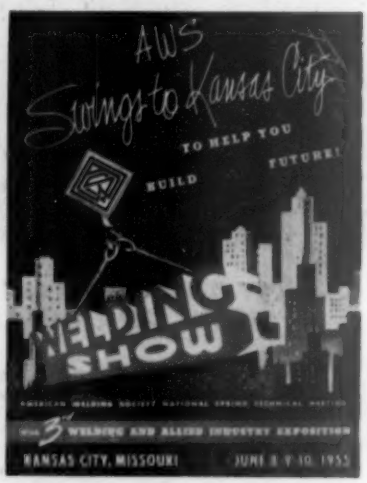
Seems Everyone Is Coming to K. C.!

Kansas City hotels are now confirming hotel accommodations to those who applied. They are facing quite a problem because the demand from people who plan to attend the AWS 1955 Spring Meeting and Welding Show is far greater than was expected. The town will be "bursting at the seams" and it would not be surprising if the Mayor, at the Governor's request, were to declare June 7 to 10, *AWS Week!*

When hotel reservation forms were first sent out by AWS headquarters, everyone was asked to name a selection of five hotels because, as stated, Kansas City hotels are *not large*-all are good. Many members specified only one hotel but, unfortunately, no one hotel, or two or three for that matter, can accommodate the demand.

There will be enough room for all who plan to be in Kansas City, but many, many AWS members are asked to help their fellow members by accepting the excellent accommodations offered to them by *all* the K. C. hotels. By doing so, they will be provided far greater comfort. Nearly all the hotels are very close (walking distance of 1 to 4 blocks) to the Auditorium and the meeting sessions.



Section News and Events

as reported to Catherine O'Leary

BRAZING

Albuquerque, N. Mex.—K. V. Lutz AWS, of the All State Welding Alloys Co., White Plains, N. Y., was the guest speaker at the February 18th meeting of the *Albuquerque* Section held in the Industrial Arts Building of the University of New Mexico. Mr. Lutz talked about low heat alloy rods. He also had about an hour and a half demonstration on low temperature welding.

RESISTANCE WELDING APPLICATION

Phoenix, Ariz.—J. H. Cooper AWS, of the Taylor Winfield Corp., was the speaker at the February 16th meeting of the *Arizona* Section. Mr. Cooper's talk covered Resistance Welding Application and was illustrated with slides.

NON-DESTRUCTIVE TESTING

Boston, Mass.—The regular monthly meeting of the *Boston* Section was held at the Westinghouse Auditorium, Boston, Mass., on Feb. 14, 1955, in connection with the Society for Nondestructive Testing.

After the usual Social Hour and dinner, about 130 members and guests enjoyed an excellent talk by "Bump" Hadley, former major league baseball player and radio and TV announcer.

The technical speaker of the evening was Carlton H. Hastings, Chief, Non-Destructive Testing Branch, Watertown Arsenal, whose subject was "Modern Methods and Techniques for the Non-Destructive Testing of Weldments." He covered all phases of the subject completely from X-ray to ultrasonic testing, including dye penetrants, flourescent, and others. Although the talk lasted for 90 min., it was enjoyed very much by those interested in this subject, and it was the opinion of those present that Mr. Hastings is indeed an expert in this field both from the technical and the practical standpoint.

STRUCTURAL CONNECTIONS

Chicago, Ill.—On Friday, February 18th, nearly one hundred members of the *Chicago* Section attended the meeting in the Peoples Gas, Light, and Coke Co. Auditorium. Professor R. S. Green AWS, of Ohio State University, spoke on "Design of Welded Structures."

Professor Green reviewed specific design problems and discussed several types of structural connections using a variety of rolled sections. Critical design steps relating to roof trusses, girders, beams and columns were explained. Of course the interrelationship of welding procedures and quality control with good welding design was explained.

A lively question and answer period attested to Professor Green's excellent presentation, along with the interest in his subject.

Preceding the usual social hour at Burke's Grill was a meeting of the Board of Directors of the Chicago Section.

Amel R. Meyer, chairman, reported on the Midwest Welding Conference which attracted almost two hundred members and others interested in welding and brazing. Questionnaires

SECTION MEETING CALENDAR

MAY 6th

NORTH CENTRAL OHIO Section. 6:30 P.M. Bucyrus, Ohio.

MAY 10th

DAYTON Section. Plant Visitation.

MAY 12th

SAGINAW VALLEY Section. All Day Welding Symposium and Welding Demonstrations at General Motors Institute, Flint, Mich.

MAY 14th

DETROIT Section. Ladies Night Party, 6 P.M. Latin Quarter, 3067 East Grand Blvd. near Woodward Ave.

MAY 16th

ROCHESTER Section. Rochester, N. Y. Annual meeting and election of officers.

MAY 17th

NEW JERSEY Section. Newark, N. J. Special Year-End Meeting.

TOLEDO Section. Annual May Dinner.

MAY 19th

NORTHERN NEW YORK Section. Schenectady, N. Y. Annual Meeting. Ladies' Night.

RICHMOND Section. Richmond, Va. "Latest Methods of Joining Aluminum by Welding Brazing and Soldering," by Charles Bruno Reynolds Metals Co., Louisville, Ky.

MAY 20th

CHICAGO Section. "Inspection of Welds" by Levi Tarr, Philipps Petroleum Co.

MAY 21st

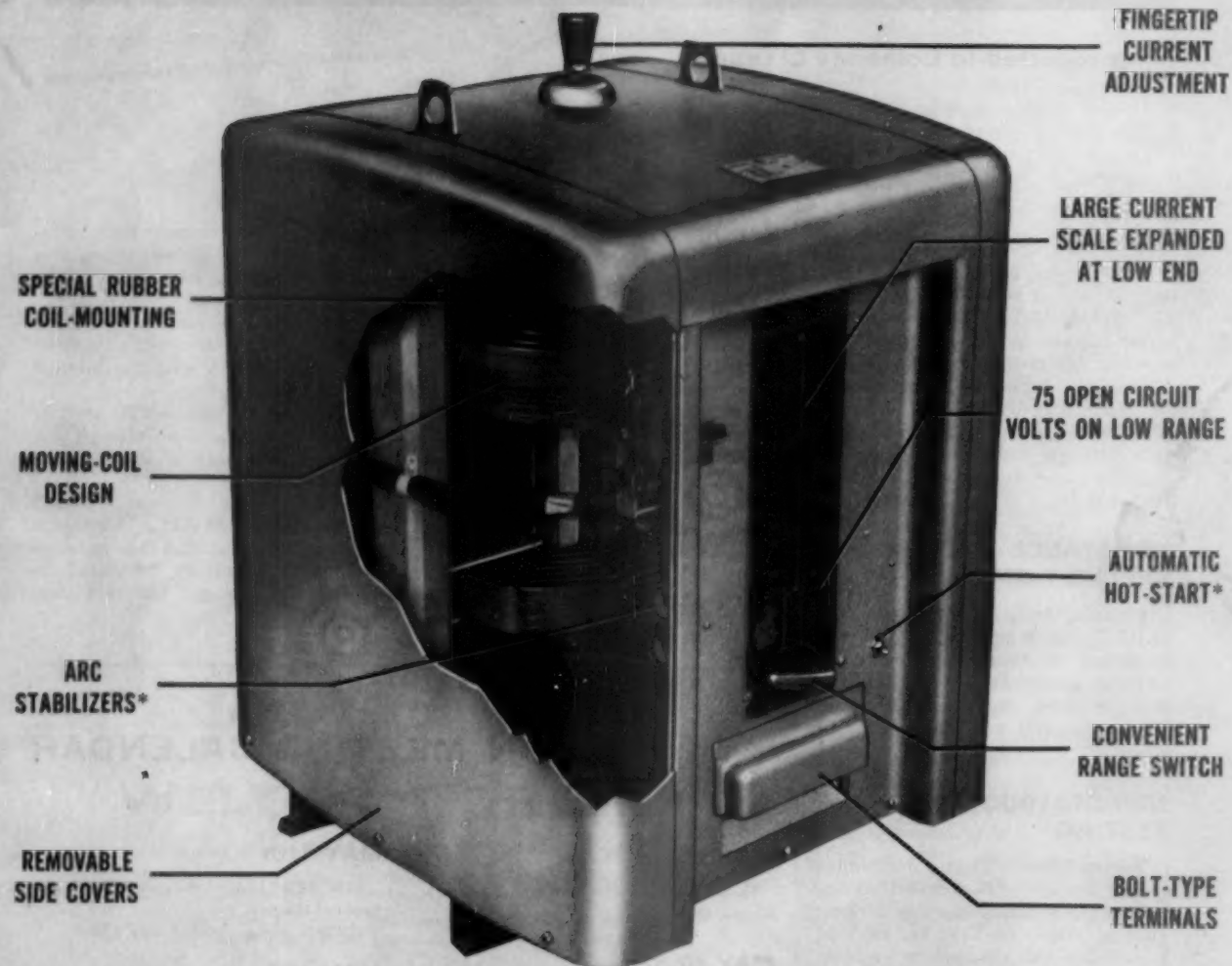
MILWAUKEE Section. May Party.

MAY 25th

NORTHERN PENNSYLVANIA Section. Erie, Pa. Annual Meeting.

Editor's Note: Notices to be published in any one given issue must reach Journal office not later than the first of the preceding month. Give full information concerning time, place, topic and speaker for meeting.

WELDING ARCS NEWS



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Florida: Hollywood—Florida Gas & Chemical

Georgia: Athens—Welding Gas Products; Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies; Gainesville—Welding Gas Products

Idaho: Boise—Gate City Steel

Illinois: Chicago, Moline, Rockford—Machinery & Welder

Indiana: Evansville—Drillmaster Supply; Ft. Wayne, Indianapolis—Sutton-Garten; South Bend—Perry Welding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Wichita—Standard Products

Kentucky: Louisville—Reliable Welding; Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Orleans—Industrial Air Products of the South

Maine: South Portland—Portland Welding Supply

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit, Saginaw—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Greenwood—Delta Oxygen Co.; Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply; Billings, Bozeman, Cut Bank, Glasgow, Great Falls, Havre, Kalispell, Miles City, Shelby, Sidney, Whitefish—Valley Motor Supply; Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Hampshire: Manchester, Nashua—MacLeod Co.

New Jersey: Elizabeth—Interstate Welding Supply

New Mexico: Albuquerque—Industrial Supply Co.; Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

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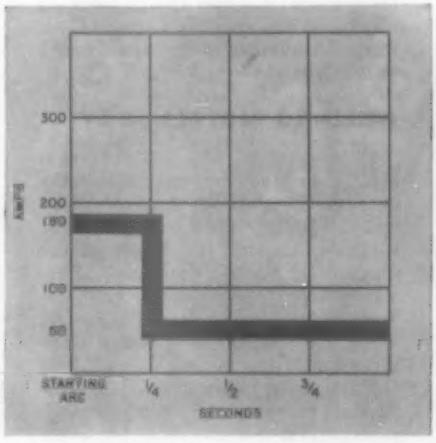
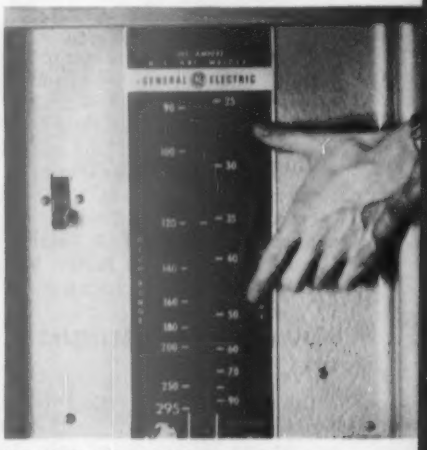
EACH SIDE COVER LIFTS OFF easily, with removal of only 3 screws. And no parts are attached. Simple inside construction can be serviced quickly.



AUTOMATIC HOT-START provides an extra surge of current when electrode touches the work. Arc striking is instant; sticking is reduced. Result: welding speed is increased and weld quality improved.



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Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works; Youngstown—Arcway Equipment Co.

Oklahoma: Oklahoma City—Hooper Supply; Tulsa—G-E Welding Sales Division

Oregon: Eugene, Portland—J. E. Haseltine; Medford, Portland—Industrial Air Products

Pennsylvania: Allentown, Philadelphia, Pittsburgh, York—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff; Lemmon—Valley Motor Supply Co.

Tennessee: Chattanooga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Welding Equipment & Supply; Beaumont—Beaumont Oxygen; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Houston—G-E Welding Sales Division; Lubbock—Welders Supply of Lubbock; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Orange—Marine & Petroleum Supply; Pecos—Welding Supply Co.; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—McGinnis Welding Supply

Utah: Salt Lake City—The Gallagher Co.

Washington: Seattle, Spokane—J. E. Haseltine; Seattle, Spokane, Yakima—Industrial Air Products

West Virginia: Bluefield—Bluefield Supply; Charleston—Virginian Electric; Huntington, Logan—Logan Hardware & Supply

Wisconsin: Milwaukee—Machinery & Welder

Wyoming: Cody, Lovell—Valley Motor Supply Co.

Alaska: Anchorage—Northern Supply

Canada: Toronto—Canadian G.E.

Guam: Agana—Industrial Air Products Div. of Island Equipment Co.

Hawaii: Honolulu—American Factors, Ltd.

AT THE FEBRUARY MEETING OF THE CHICAGO SECTION

Bill Lilly's talented and sweet granddaughter entertained at dinner time. That's Bill smiling on the right

Professor Green, the principal speaker, drives home an important point during his talk on "Design of Welded Structures"

Part of the large crowd that attended the meeting in the Auditorium of the Peoples Gas, Light and Coke Co.

passed out at the meetings showed a fine reaction by the audience and will aid in setting up next year's conference which is to be co-sponsored with Armour Research Foundation again. Mr. Meyer thanked Orville T. Barnett, special activities chairman, for his part in the Midwest Welding Conference.

WELDING YOUR FUTURE

Cleveland, Ohio—"Welding Your Future" was the title of an unusual program presented over WNBK-TV, Sunday, January 16th. Produced by the *Cleveland* Section, the program was part of the "Adventures in Engineering and Science" TV series sponsored by the Cleveland Technical Societies' Council. Full details on this event were given in the March issue of THE WELDING JOURNAL.

ADVANCED ALUMINUM WELDING

Columbus, Ohio—"Recent Advances in Aluminum Welding" was the subject of a semi-technical talk given by Paul B. Dickerson of the Aluminum Company of America at the February 11th dinner meeting of the *Columbus* Section held at the Student Union, Ohio State University. Two films on aluminum were also shown.

AUTOMATIC WELDING PROCESSES

Denver, Colo.—With an attendance of 23 at dinner and 34 at meeting, the *Colorado* Section got together on February 8th in the Festival Room of the Oxford Hotel. Coffee speaker was Don Cline of the Mountain States Telephone and Telegraph Co. who explained developments of the communication system which proved very interesting and educational.

Principal speaker was D. C. Ransone [illegible], Regional Engineer of the Linde Air Products Co., Kansas City, Mo. Mr. Ransone's subject of "Recent Developments in the Electric Automatic Welding Processes" was supported by slides of actual welding jobs. The subject was divided into three actual processes: submerged arc welding; nonconsumable-electrode inert-gas welding and consumable-electrode inert-gas welding. The value of knowing what process to use for definite jobs was brought out to the group and seemingly appreciated from the number of questions asked at the close of the talk.

WELDING METALLURGY

Dayton, Ohio—The *Dayton* Section held a joint dinner meeting with ASM on February 9th. Approximately seventy members of both technical societies attended the dinner at the Dayton Engineers Club and afterwards heard O. B. Reemelin, Vice-President of the Dayton Power and Light Co., speak on "Water Conservation in the Miami Valley." He told how the water problem in the Miami Valley is becoming acute—especially if consumption continues to increase at the same rates as in the past ten years. His solution is essentially controlled flow rates of the river which will help to keep the river bed clean and allow water to pass from the underground reserves to the river and vice versa as the need requires.

The main talk of the evening was given by George E. Linnert [illegible], Research Welding Metallurgist of the Research Laboratories of Armco Steel Corp. in Baltimore, Maryland. Mr. Linnert emphasized the importance of welding metallurgy in fabrication of steel weldments. Various types of weldment failures were shown because of neglect to observe fundamental metallurgical practices. Other types of failures were also shown that required quite a bit of metallurgical sleuthing to determine the cause of the failure. Corrosion problems encountered in the weld affected zone and the weld metal of stainless steel weldments were thoroughly discussed. Approximately 200 members of both societies attended the meeting.

ACTIVATION MEETING

San Antonio, Tex.—Some fifty persons attended an activation meeting held on Dec. 6, 1954, by the San Antonio Division of the *Houston* Section.

ORGANIZATIONAL MEETING

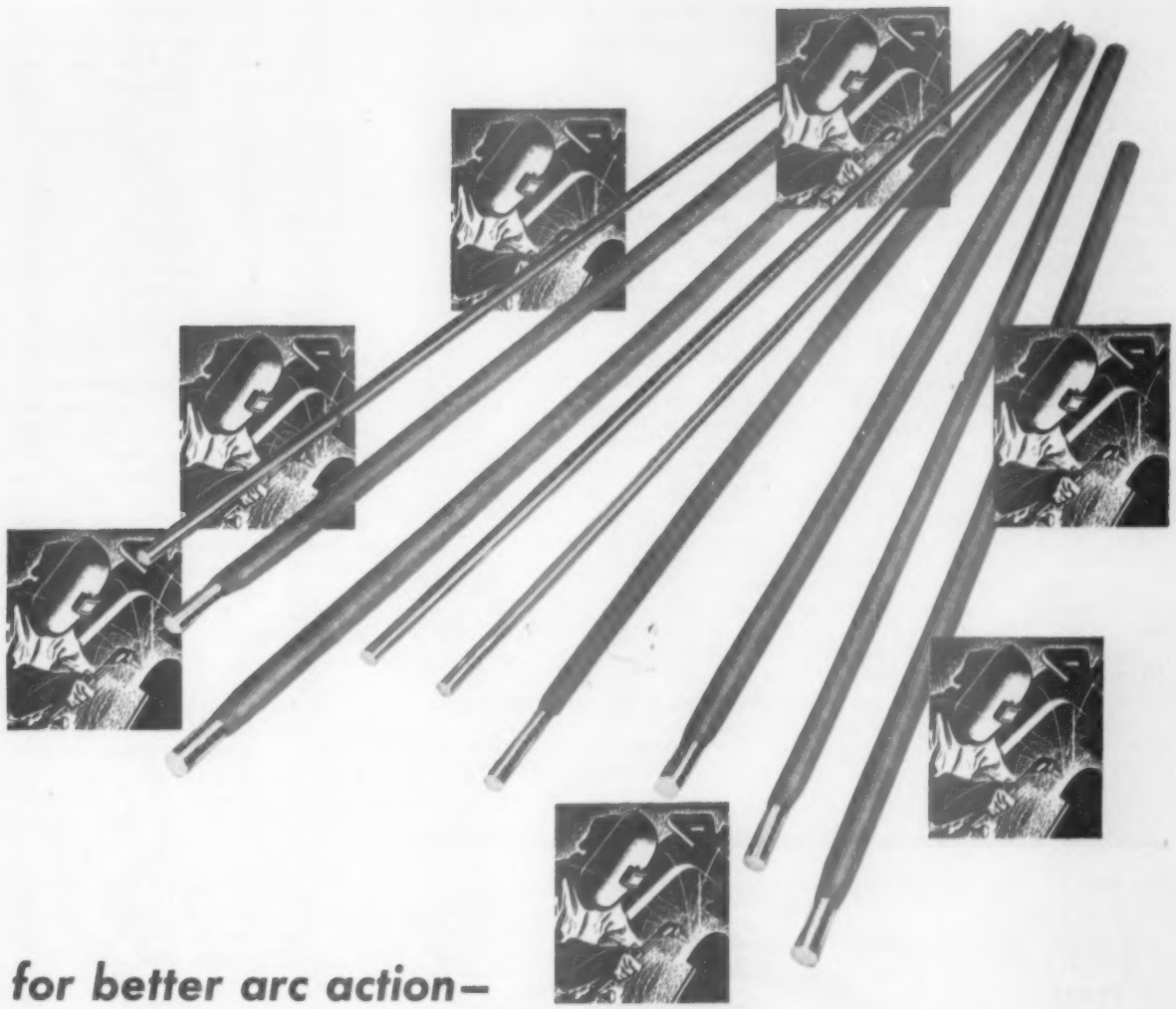
San Antonio, Tex.—The San Antonio Division of the *Houston* Section held its first meeting on Tuesday, January 25th. It was a huge success.. Sixty-eight new members were signed up including three supporting company memberships.

CONTACT WELDING ELECTRODES

Houston, Tex.—One hundred and thirteen members and guests of the *Houston* Section were present at the monthly dinner meeting held on January 26th at the Ben Milam Hotel. A social period preceded the dinner. The guest speaker was E. Diliberti [illegible], of the Air Reduction Sales Co., New York. The topic discussed by Mr. Diliberti was "The Advantages and Disadvantages of Contact Welding Electrodes." The talk was very informative, semi-technical in scope, and enlightening on this current and important subject. Slides and high speed motion pictures were used to illustrate the talk. Mr. Diliberti is assistant manager, Equipment Sales. He has full responsibility for both sales and technical phases of welding electrodes and hard facing products handled by Air Reduction.

STRESS RELIEVING

Beaumont, Tex.—An excellent talk



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by one of the local men was given on February 24th at the Sabine Division of the *Houston* Section meeting held at the Hotel Edson. The speaker was George P. Trotter, Jr. [illegible], of the Gulf Oil Corp., Port Arthur. Mr. Trotter's talk "Practical Aspects of Relieving Stresses Caused by Welding" covered by "why," "how," and "results" of stress relieving, a procedure very important to modern welding. After his talk, Mr. Trotter conducted a question and answer period.

Through the courtesy of the Shell Oil Co., an all color film on "Birth of an Oilfield" was shown. This film shows how an oil well is drilled and how crude oil is brought up from the ground and started on its way to the refinery.

SILVER BRAZING

Houston, Tex.—The *Houston* Section held its regular monthly meeting on February 23rd. A buffet barbecue preceded the technical session.

Philip G. Deuchler of Handy and Harman's field engineering staff was the speaker for the evening. Mr. Deuchler gave a very enlightening talk on the subject, "Production Silver Brazing."

RESISTANCE WELDING APPLICATIONS

Indianapolis, Ind.—The *Indiana* Section held its January meeting on Friday, January 28, 1955 at Buckley's Restaurant in Cumberland, Ind. The dinner was followed by a short business meeting and announcements of coming activities.

The membership was then treated to a film on the origin, and usage of the oxy-acetylene flame made available by the National Cylinder Gas Co., which proved most interesting as well as informative.

The main part of the program, however, was a talk and slide film illustration of "Resistance Welding Applications" given by J. H. Cooper [illegible], of the Taylor-Winfield Corp. This centered mainly around resistance welding problems in the automotive field and the many and varied applications needed by this industry.

Approximately fifty members and guests were in attendance at this meeting.

DESIGN FOR WELDING

Des Moines, Iowa—Another large group of the *Iowa* Section met at the Kirkwood Hotel, Des Moines, February 17th, to listen to a talk that is forever timely in the welding game—that of designing products for welding. R. H. Bennewitz [illegible], Linde Air Products, Kansas City, after a delicious family style fried chicken dinner related the old story once again but with a new and more comprehensive approach. His topic title was "Improved Design for Welding." It was aimed at the designer but actually involved anyone concerned with welding since materials, processes and applications are all given consideration.

In treating an application, one first has to consider materials available, then choose an appropriate process. This can be done easiest by charting materials against welding processes with a code system to establish all the desirable or undesirable properties of each.

Next, the production equipment available must be known to obtain an accurate and economical choice of welding process. Along with such knowledge also goes the factor of floor space.

Fixture requirements should next be charted in a similar fashion to the process vs. materials charts so as to direct attention to the basic fundamentals necessary for design of a fixture which will fit the welding process.

Many individual questions were answered following the talk. It was a pleasure to note that many members and guests had come singly and in groups from cities quite distant from Des Moines.

LOW HYDROGEN ELECTRODES

Kansas City, Mo.—R. K. Lee [illegible], vice-president Alloy Rods Co., York, Pa., was the guest speaker at the January 13th meeting of the *Kansas City* Section held in Fred Harvey's Pine Room, Union Station. Mr. Lee's excellent talk on "Low Hydrogen Electrodes" was illustrated with lantern slides.

SUBMERGED ARC WELDING

Kansas City, Mo.—One of the members of the *Kansas City* Section, D. C. Ransome of the Linde Air Products Co., was the speaker at the February 10th meeting. Mr. Ransome's talk entitled "Submerged Arc Welding" covered both single electrode welding and multiple electrode welding. In the case of multiple electrodes the speaker covered both electrical parallel electrodes and multi-power electrodes. In both cases of multiple electrodes

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the various electrical connections were discussed.

INERT ARC WELDING

Bethpage, L. I.—The February meeting of the *Long Island* Section was held on Thursday, February 10th, at Anselmi's Restaurant, Bethpage, L. I. Preceding the technical meeting, a very excellent color and sound film secured from the Grumman Aircraft Engineering Co., Bethpage, was shown. This film showed the trials of Grumman's SA 16 Triphibian plane, the "Albatross," on land, snow, ice and water. The plane is currently in use by the Army, Navy and Coast Guard for rescue work.

Speaker of the evening was Harry A. Huff, Jr. AWS, of the Air Reduction Sales Co., New York City. Mr. Huff's topic was on general applications of the welding of aluminum and stainless steel by the inert gas-shielded arc welding process.

AUTOMATIC WELDING

Louisville, Ky.—The *Louisville* Section opened the New Year's activities with a well-attended technical meeting containing several special features on Tuesday evening, January 25th. The Section took due note of its meeting falling within "YMCA Week" by having Mr. Ralph Brunson of the downtown "Y" as a coffee speaker. Mr. Brunson presented a brief but very interesting story of the start of the "Y" movement and of the present expansion of the Louisville Y into Greater Louisville.

The Louisville Section welcomed John H. Blankenbuehler, Troy, Ohio, director of the 5th AWS District. Last fall the Louisville Section was shifted from the old 6th District to the new 5th District under Mr. Blankenbuehler. He urged his audience to fill up all cars driven to our monthly meetings as a means of getting prospective members to these meetings, and thus building up broader interest and benefits. This means also to help non-driving members to get to the meetings more easily. He described the last meeting of the Dayton, Ohio, Section, which was a "Welding Quiz Program with Panel"—and prizes.

The main speaker, Mr. Harley Orr, engineer in charge of automatic welding application engineering for the Hobart Bros. Co., Troy, Ohio, used very clear slides effectively to aid his description of his company's "Constant Voltage Process for Automatic Welding." The slide diagrams emphasized the simplicity of the controls developed for the several methods for arc welding automatically. His brief explanation gave an excellent chance for questions and discussions. Mr. Blankenbuehler also aided in furnishing information to questioners. The good turn-out of members and visitors took ample advantage of this discussion period.

WELDING METALLURGY

Madison, Wis.—The January dinner meeting of the *Madison* Section was held on January 27th at the Playdium. Following the dinner and business meeting, the meeting was turned over to Arnold Ehle for the technical meeting. Speaker was Anton Schaeffler AWS, of Allis-Chalmers, whose subject was "Metallurgy and Welding."

FABRICATING PROCEDURE

Warren, Ohio—"Fabricating Procedure in a Job Shop" was the subject of a talk given by J. R. Stitt AWS, research and welding engineer, the R. C. Mahon Co., Detroit, Mich., at the February 17th dinner meeting of the *Mahoning Valley* Section held at the El Rio Restaurant. Mr. Stitt presented his subject in a very informative manner, particularly covering stress distribution in welded joints as produced by expansion, contraction, distortion and residual stresses. A clear picture of these important individual factors was illustrated with slides and film. With the aid of film, Mr. Stitt also spoke and illustrated "straightening of bent and distorted heavy rolled steel structural sections employing oxy-acetylene flame."

RESISTANCE WELDING

Baltimore, Md.—The February meeting of the *Maryland* Section was held at the Engineers' Club, Baltimore, on February 18th.

Immediately following the dinner, J. R. Minihan delivered a very interesting coffee talk entitled "A Trip Around the World," which held the audience captivated.

The technical session, "Principles of Resistance Welding," was presented by William J. Farrell AWS, chief application engineer, Sciaky Bros., Inc., of Chicago, Ill.

Mr. Farrell explained the principles of spot, projection, seam, and flash-butt welding processes, and showed many slides to illustrate the uses of these processes in various industrial applications. The size and diversity of some of these machines was indeed astounding.

Mr. Farrell kept his description of the processes simple, for the benefit of

those persons unfamiliar with the resistance methods of welding, but was so thorough in his explanations that many of those in attendance gained valuable new knowledge of resistance welding.

ELECTRODE COATINGS

Mishawaka, Ind.—A dinner meeting was held by the *Michiana* Section on February 17th at the Red Barn Restaurant just north of Mishawaka, Ind. The fried chicken and trimmings, country style, were up to the usual standard of quality and quantity served by the restaurant and it was enjoyed by all.

A. Clemens, Jr. AWS, director of research and welding engineering, Arcrods Corp., Sparrows Point, Md., was the technical speaker. His subject was "Recent Developments in Electrode Coatings." A number of pertinent questions were asked by the audience. The resulting comments by the speaker were a clarification of a very timely subject. The Section is very appreciative of the excellent talk given by Mr. Clemens.

ORGANIZATION MEETING

Omaha, Nebr.—The first meeting was held Oct. 10, 1954, at the Birchwood Club, Omaha, to organize the *Nebraska* Section. The meeting was called to order by Professor S. V. Williams, staff member, University of Omaha. Professor Williams gave an interesting talk on the subject "Modern Welding and the American Way of Life" which was enjoyed by all present.

The following officers were elected:

Chairman—Prof. S. V. Williams
First Vice-Chairman—Paul Y. Smith
Second Vice-Chairman—F. L. Pflasterer
Secretary—Dave Breslow
Treasurer—W. O. Schneiderwind

WELDABILITY OF STEEL

Newark, N. J.—Approximately one hundred members and guests attended the February 15th meeting of the *New Jersey* Section held at the Essex House, Newark.

Dinner at 6:30 followed an Executive Committee meeting which met at 5:15. The coffee speaker was S. D. Page, Public Relation Supervisor at Bell Telephone Co. Mr. Page spoke on and demonstrated the uses of transistors in various types of electronic equipment.

The featured speaker was Professor R. D. Stout AWS, professor of metallurgy at Lehigh University. Professor Stout spoke on the weldability of steel and also discussed some of the

Chairman Ken Koopman and guest speaker Bob Stout at the February Meeting, New Jersey Section

problems and extensive investigations of pressure vessels being carried on by the College. Professor Stout received his B.S. degree from Penn State, and was then connected with Carpenter Steel Co. for four years. He continued his studies at Lehigh, and received his Ph.D in 1944. Prof. Stout has been on the staff at Lehigh since 1939.

The quiz session was conducted by William Apblett, manager of welding laboratory at Foster Wheeler Corp. in Carteret.

The usual after meeting snack and get-together was enjoyed by all.

MARINE WELDING SYMPOSIUM

New York, N. Y.—A symposium on Marine welding practices was held in a joint meeting of the New York Section with the Society of Naval Architects and Marine Engineers on February 24th.

The symposium was led by Wm. B. Jupp, manager of the Construction and Repair Division of the Socony-Vacuum Oil Co., and the speakers were Carl M. Hellmer, welding engineer for the General Electric Co., J. H. Hunt AWS, welding engineer for Combustion Engineering, Inc., and John Mikulak AWS, assistant to vice-president in charge of manufacturing, Worthington Corp. The topics presented were welding practices in regard to marine turbine, marine boilers, and heat exchangers. A large number of slides were shown which gave the audience a clear picture of the topics and Mr. Jupp led the symposium through an extensive question and answer period.

The turnout was unusually large, in excess of 250, and the meeting was held at the Antlers Restaurant, 67 Wall St., New York, where dinner was served prior to the technical session.

JOB SHOP FABRICATION

Buffalo, N. Y.—The *Niagara Frontier* section held a dinner meeting on January 27th in the Sheraton Hotel. Speaker was J. W. Mortimer AWS, of the Whitlock Manufacturing Co. His subject was "Fabrication in a Job Shop."

WELDING PROCEDURES

Marion, Ohio—The February meeting of the *North Central Ohio* Section was held on the 4th in Marion at Hotel Harding. Approximately 55 members and guests attended. A movie showing the story of copper from mining to final refining was shown through the courtesy of the Phelps Dodge Corp.

J. R. Stitt AWS, research and welding engineer for the R. C. Mahon Co., Detroit, gave an extremely interesting talk on "Welding Procedures and Distortion Control." Mr. Stitt discussed, at length, heat forming and showed many interesting pictures of salvage operations accomplished by means of heat forming. The question and answer period lasted until midnight, which is evidence of an extremely interesting presentation.

The following new members were introduced at the meeting. Irving Dutt and Ellis C. Wilson, both of Marion Power Shovel Co.; Glenn Wright of F. E. Myers Co.; C. E. Henderson, Lima, Ohio, and John Bergeron, Mansfield, Ohio.

NON-DESTRUCTIVE TESTING

Menands, N. Y.—The *Northern New York* Section held its monthly meeting on February 3rd in Panetta's Restaurant, Menands, New York.

The topic discussed at the meeting was "Non-Destructive Testing of Weldments" and was given by Charles D. Moriarty of the General Electric Co. Mr. Moriarty is currently manager of the non-destructive testing sub-section of the Large Steam Turbine Generator Department, Materials and Processes Laboratory. Since 1928 he has been engaged in non-destructive testing work and has pioneered in many present day applications. Notable in these pioneer jobs was the introduction of million volt X-ray in 1940, and the combining of X-ray and photoelectric tubes in 1943, and the use of ultrasonics in industry in 1944.

Mr. Moriarty traced the use of X-ray as a nondestructive means of testing weldments from low voltage equipment to the present day betatron as the section thickness of weldments increased. He discussed the use of magnetic particle and liquid penetrant tests as means of detecting surface defects in welds. He also discussed

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the use of ultrasonics which currently has rather limited application but which he feels will become a valuable tool for the testing of weldments after further development work.

INERT ARC PROCESS

Erie, Pa.—The subject of the February 16th meeting of the *Northwestern Pennsylvania* Section was of timely interest as evidenced by the large turnout and participation of the audience during the question and answer period. John McKenzie [illegible], Linde Air Products, Engineering Service Department, can be credited with an excellent presentation of the consumable-electrode inert-gas welding process and answered specific questions about procedure for many of the users of this process. In particular, he pointed out that welding with d-c straight polarity causes deep penetration with a narrow bead, while d-c reverse polarity causes a wide bead with very shallow penetration. Using a-c with a high frequency stabilizer results in a bead that is an approximate average of the two previously mentioned methods; that is, narrower than when using d-c reverse polarity and considerably deeper. Samples of work welded by the inert-arc process were passed among the audience to exemplify some typical applications.

INERT ARC WELDING

Pittsburgh, Pa.—"Inert Gas Metal Arc Welding Carbon Steel" was the subject chosen for a semi-technical discussion by J. R. Craig [illegible], eastern region engineer, Linde Air Products Co. at the February 16th meeting of the *Pittsburgh* Section. Dinner in the Hunt Room of the Hotel Webster Hall preceded the meeting held at Mellon Institute. Slides and motion pictures were used to illustrate some of the discussion.

Plans were announced for the annual tri-state conference scheduled for April 29th.

BULL RUN PIPELINE

Portland, Ore.—The fifth meeting of the 1954–55 season for the *Portland* Section was held Thursday evening, February 10th, at the Heathman Hotel, Portland, Ore.

A social period and dinner was followed by a very interesting movie showing the fabrication and laying of the Bull Run pipeline, which supplies water to the City of Portland. This line is the largest in this area, and the story was of interest to everyone in the metals trades industry in this area.

WELD INSERT PROCESS

Rochester, N. Y.—An interesting and complete description of the E-B (electric boat) weld inserts process was given by Jim Norcross [illegible], of Arcos Corp. at the January 17th meeting of the *Rochester* Section. The assembly, tolerances and advantages of this type of welding process were discussed. The greatest advantage gained by using an insert of this type is when only one side of the joint is available to the welder, so explained Mr. Norcross. Along with his discussion, Mr. Norcross showed some slides which clarified any questions that might have arisen.

STUMPING THE EXPERTS

Rochester, N. Y.—The Liederkranz Club in Rochester was again host to the *Rochester* Section on February 21st where an enjoyable dinner took place before the regular business meeting and activities for the evening.

This month's activities involved a "Stump the Experts" panel where three teams comprised of three members answered questions pertaining to welding and were graded accordingly by three judges chosen by the committee.

Through this meeting the Section found that they had quite a number of experts including those in the audience. The team members were as follows:

Team No. 1—Walter Kazoroski, Bob Waldsvogel and Steve Danes
Team No. 2—Alton Babcock, Fred Hall and Don Masterson
Team No. 3—Frank Comisso, Clyde Martin and Gomer Stelljes

The judges for the evening were Nelson Martin, William Weber and Harvey Ainsworth. The master of ceremonies was George Davies.

Bill Nash did an excellent job of securing the panel members and general planning of the teams involved.

This type of meeting seemed to be thoroughly enjoyed by all present and a consensus of opinion was that the Section members would like to have a meeting of this type at least once a year.

DINNER DANCE

Saginaw, Mich.—The Annual Valentine Dinner Dance of the *Saginaw Valley* Section was held at Saginaw on January 25th. The affair was attended by 131 couples. The ladies were furnished with corsages. A majority of the couples present won door prizes of merchandise. This affair was a complete sellout and was a great success.

WITH THE TUCSON SECTION AT THE JANUARY MEETING

The January 18th meeting of the Tucson Section was a tremendous success. More than 250 members and guests were in attendance to witness practical demonstrations in inert-arc welding with both consumable and non-consumable electrode. Part of the large crowd is shown here

Pictured here are the members of the Executive Committee of the Tucson Section (*left to right*): Albert Denn; Richard Smith; Robert Smith, *Vice-Chairman*; George Hunt; Dewey White; Joseph Pruitt, *Past Junior Vice-Chairman*; Dean Tillotson; Joe Brennan, *Chairman*; and Charles Condron

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STRUCTURAL JOINTS

Miami, Fla.—A. E. Pearson, director of District No. 4, and chief welding engineer of the Ingalls Iron Works, Birmingham, Ala. was the guest speaker at the January 16th meeting of the *South Florida* Section. Mr. Pearson gave a very interesting talk on structural welding joints, illustrated with slides and held a forty minute question and answer period.

A dinner and business meeting at the Seven Seas Restaurant took place before the technical meeting which was held at Builders Exchange Building. Plans for the remainder of the season were discussed at the business meeting. It was decided to hold a buffet dinner, pre-cocktail hour, and have a coffee speaker for the May meeting.

Two teams were selected for a membership drive being put on by the Section. The losing team will sponsor a dinner for the winners.

URANIUM

Tucson, Ariz.—A dinner meeting of the *Tucson* Section was held on February 15th at Randolph Municipal Club House. Jack Clark of the Arizona Bureau of Mines and Extension Division of the University of Arizona was the speaker. Mr. Clark spoke on the prevalence of uranium in Southern Arizona, showed samples of various uranium ores, demonstrated the operation of a Geiger counter and offered many suggestions relative to prospecting for this metal, as well as the procedure in making a claim. This was a particularly interesting talk to all the members in regard to the recent activity in uranium in this area, and the talk was very well received.

STEEL SPANS THE CHESAPEAKE

Washington, D. C.—The erection of a 4-mile steel bridge across Chesapeake Bay was the theme of a picture shown through the courtesy of Bethlehem Steel as a feature of the January 25th meeting of the *Washington* Section. This film shows the erection of one of the world's longest steel highway bridges. Stretching 4 miles across Chesapeake Bay, the superstructure contains almost every known type of bridge span—beam, deck girder, deck truss, through truss, cantilever and suspension spans.

The method used to build up the deep-water piers from the bay bottom is shown by animated drawings. Colorful photography follows the erection of each of the principal types of spans. It shows how some of these were assembled on a dock located out in the bay, floated on barges and placed on the piers; and how other units were assembled in position, using a special tower derrick boat and traveling derricks.

Scenes covering the construction of the suspension span describe the erection of the towers, the laying of the main cables, the hoisting of the roadway sections.

PANEL DISCUSSION

Grand Rapids, Mich.—The *Western Michigan* Section held its regular monthly meeting on January 24th at Varsity Grille. Present for the dinner were 70 members and guests who were joined by a few more for the meeting. A coffee talk was given by Al Ripstra of the Better Business Bureau of the Grand Rapids Chamber of Commerce. Mr. Ripstra's talk on "Investigate Before You Invest" was very interesting and several of the members asked to have him for the main feature of a meeting at another date.

The Technical Session was in the form of a panel discussion. The moderator, John Borman of the Clark Equipment Co. had the questions mailed in by the members at large and carded for use by the different panel members. The panel consisted of the following: Stuart Spice and Wm. F. Williams of the Buick Motor Co.; John F. Randall of the Ford Motor Co.; Ralph McNitt of the Oldsmobile Co.; Dr. A. J. Smith of the Metallurgical Dept. of M. S. C. and Chas. W. Sparrow welding engineer of Purity Cylinder Gases, Grand Rapids, Mich.

The meeting was very interesting and several lively discussions followed. One of the most interesting was propane versus acetylene for cutting.

Three new members were signed during the evening making a total of 121 to date, this being the highest number of members the Western Michigan Section has ever attained.

PLANT TOUR

York, Pa.—Members of the *York-Central Pennsylvania* Section toured the S. Morgan Smith Co. Plant on February 15th and were shown the operation of the plant's new $40,000 high precision Lumotrace projector located in a cubical under the roof of Plant 2 which is approximately 65 feet from floor level.

The projector, a German import, is designed for layout work in plate shops and has been adopted for use at Smitheo. The layout is made on a scale of 10 to 1 and shows all necessary markings such as hole spacings, and cutting information. These tracings are prepared on a glass process which does not become affected by temperature or moisture shrinkage. These are further reduced to slides $2^1/_2$ x 3 in for the projector. The projector then can cast full size images onto a 10 ft x 40 ft plate layed out on the layout table from which the image lines can be painted upon this plate. To compensate for the slight imperfection of the lens, a camber is induced at the center of the plate which amounts to approximately $1^1/_2$ in for a 40 ft. long plate and decreases for shorter lengths.

The projector is operated from a central box at the base of operation on the plate and can be moved in two directions, horizontally and also vertically.

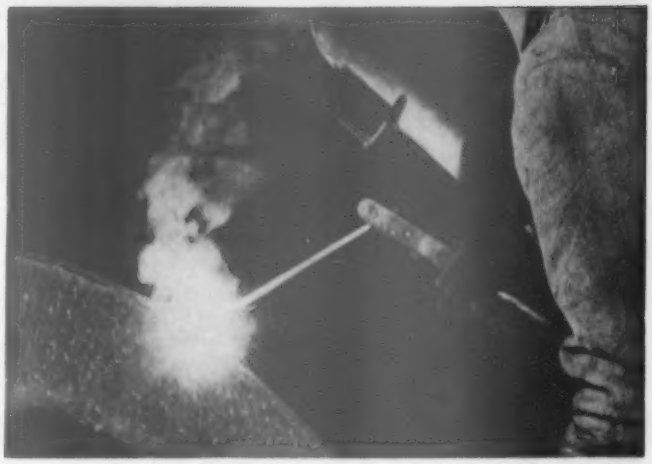
It was of further interest to know that this is the first installation of its kind in the United States.

York, Pa—Fritz Hessemer describing the operation of the Lumotrace Machine to the members of the *York-Central Pennsylvania* Section during the group's visit at the S. Morgan Smith Plant, in York, Pa., on February 15th.

Made to Last by Hard-Facing

19 LIVES FOR CONCRETE MIXER BLADES

Concrete mixer blades hard-faced with Haystellite tungsten carbide rod have 19 times the life of unprotected cast steel blades. The hard-faced blades, used in making concrete blocks, now give 20 months of tough service operating 24 hours a day, six days a week. Unprotected blades had to be replaced every four to five weeks.



NO MORE MONTHLY MAINTENANCE

This mud gun screw lasts for 8 to 10 months after being hard-faced with Haynes Stellite alloy No. 1. A single application of Haynes Stellite hard-facing rod eliminates at least seven shutdowns for repair. The screws previously had to be built up every month with steel rod because of severe wear on the flights.

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New Members

Effective January 31, 1955

MEMBERSHIP CLASSIFICATION

A—Sustaining Member B—Member C—Associate Member D—Student Member E—Honorary Member F—Life Member

ATLANTA

Malott, Charles L. (B)

BIRMINGHAM

Yadron, Peter A. (B)

BOSTON

Bodge, Frederick G. (C)
Doody, Frederick J. (B)
Zacheus, Fred R. (B)

CANADA

Hoefer, H. W. (C)

CHICAGO

DeShon, James H. (B)
Gora, Chester M. (C)
Nielsen, Leonard L. (B)
Roberts, J. D. (C)
Rocher, Walter J. (C)
Tweed, George B. (B)

CLEVELAND

Haylett, Edward (B)
Howard, Robert (B)
Johnson, Glenn L. (C)
Lehman, Gerald H. (C)
McBride, Harry E. (C)
Rose, Kurt R. (C)

COLORADO

Schrameyer, Arnold F. (B)

DETROIT

Gerardy, Elmore (B)
Knapp, Lee (B)
Lewis, Fred M. (B)
Loud, Francis T. M. (C)
McEnally, V. L., Jr. (C)
Minard, William F. (B)
Prowse, George J. (B)
VanDeusen, John M. (B)
Zelsy, S. M. (B)

FOX VALLEY

Swagel, Harvey A. (C)

HARTFORD

Green, George L. (B)
Tartaglia, Albert A. (B)

HOLSTON VALLEY

Cox, J. Cleo (B)
Kitzmiller, Homer (B)

HOUSTON

Farrior, Abe (C)
Mercer, Howard (C)
Moseley, John W. (B)

INDIANA

Quire, Paul Allen (C)
Walter, Maurice Eugene (C)

IOWA

Papuga, Chester C. (B)
Pumroy, Richard E. (C)
Pulis, Russell R. (C)
Schmidt, Gustav (B)

KANSAS CITY

Burnidge, A. C. (B)
Cody, John T. (B)
Hargrove, Merlin T. (C)
Hoffman, F. A. (B)
Smith, Donald Harrison (B)

LONG BEACH

Brush, R. S., (C)
Clark, Forrest E. (C)
Johnson, Vance R. (C)

LONG ISLAND

Fighera, Joseph F., Sr. (B)
Fineman, Gerald G. (B)
Jerome, Sidney B. (C)
Martin, Michael A. (B)
Scavullo, Charles J. (B)

LOS ANGELES

Cradler, James P. (C)
Fuller, George Earl (C)
MacCorkle, Emmett W., Jr. (B)
Marcoux, Michael L. (C)
Nance, Gerald K. (C)
Reeves, Joseph C. (C)
Tamaki, Carl M. (C)

LOUISVILLE

Hicks, Donald E. (C)

MADISON

Bremner, John R. (C)

MARYLAND

ElVeliotis, Panagiotis (B)
Leroy, Paul G. (C)

MILWAUKEE

Archer, Fred C. (C)
Boncher, Harry P. (C)
Brauns, H. F. (C)
Heidger, Leonard (C)
Henschke, Roland Kenneth (C)

NEW JERSEY

Corby, Gerald (C)
Ives, Loyal T. (C)
Miller, Frank (B)
Rutter, Donald P. (B)
Streckfuss, Arnold J. (B)
von Rohr, H. H. (C)

NEW ORLEANS

Doussan, Cleary J. (B)
Shilstone, James M. (B)

NEW YORK

Broderick, John P. (B)
Glazer, Philip (C)
Kaye, George J. (C)
Kravett, Roger (C)
McMakin, William H. (B)
Prior, William A. (C)
Sanders, Mortimer (C)

NORTHEAST TENNESSEE

Elder, Glenn Earl (C)
Murphy, Edgar J. (B)

NORTHERN NEW YORK

Hakala, William D. (B)
Magor, James K. (D)
Zych, Stanley J. (C)

NORTHWESTERN PENNSYLVANIA

Keck, George H. (B)
Sorenson, Warren H. (B)
Stormer, H. Allen (C)

OKLAHOMA CITY

Andrews, W. F. (C)
Sampson, James I. (C)

PASCAGOULA

Howard, B. F. (B)
Watz, John (C)

PHILADELPHIA

Gummeson, P. Ulf (C)
Jenzano, John (C)
Stutman, Harry D. (B)
Svanoe, W. H. T. (B)

PITTSBURGH

Campbell, Dale M. (B)
Dudas, Michael M. (C)
Nourie, Robert L. (C)
Nourie, Thomas O. (C)
Walters, John D. (B)

PORTLAND

Rice, W. H. (C)
Steele, William E. (B)

PUGET SOUND

Lobb, Alvin E., Jr. (C)
Wanner, Fred M. (B)

SAGINAW VALLEY

Huber, William F. (C)
Rentschler, Donald O. (D)

ST. LOUIS

Blankmann, George E. (B)
Heck, August E. (B)

SAN FRANCISCO

Akita, Yoshio (B)
Stuber, Edward J. (B)

SANGAMON VALLEY

Lambie, James H. (B)

SANTA CLARA VALLEY

Pedrazzi, Laurence V. (B)
Young, Douglas (C)

SOUTH FLORIDA

Hoodwin, Herbert J. (B)

SYRACUSE

McNeil, James K. (C)

TOLEDO

Cain, Melvin (B)
Gillespie, Iran L. (C)
Morrison, Warren D. (C)
Shipman, Vernon (B)
Soule, Robert J. (B)

WASHINGTON, D. C.

Spyropoulos, Constantine (C)
Tuttle, Raymond G. (C)

WESTERN MICHIGAN

Gleason, Roy C. (C)
Heiman, Bert (C)
Sbordon, Victor G., Jr. (C)

WICHITA

Allen, Paul V. (B)

WORCESTER

Perry, J. L., Jr. (B)

YORK-CENTRAL PENNSYLVANIA

Quinn, John I. (C)
Rishel, Maurice H. (B)

NOT IN SECTIONS

Hardee, Clifford E. (C)
Konsler, J. Ellis (B)
Crocker, John T. (C)

Members Reclassified

During the month of January

Ammerman, Richard F. (C to B)

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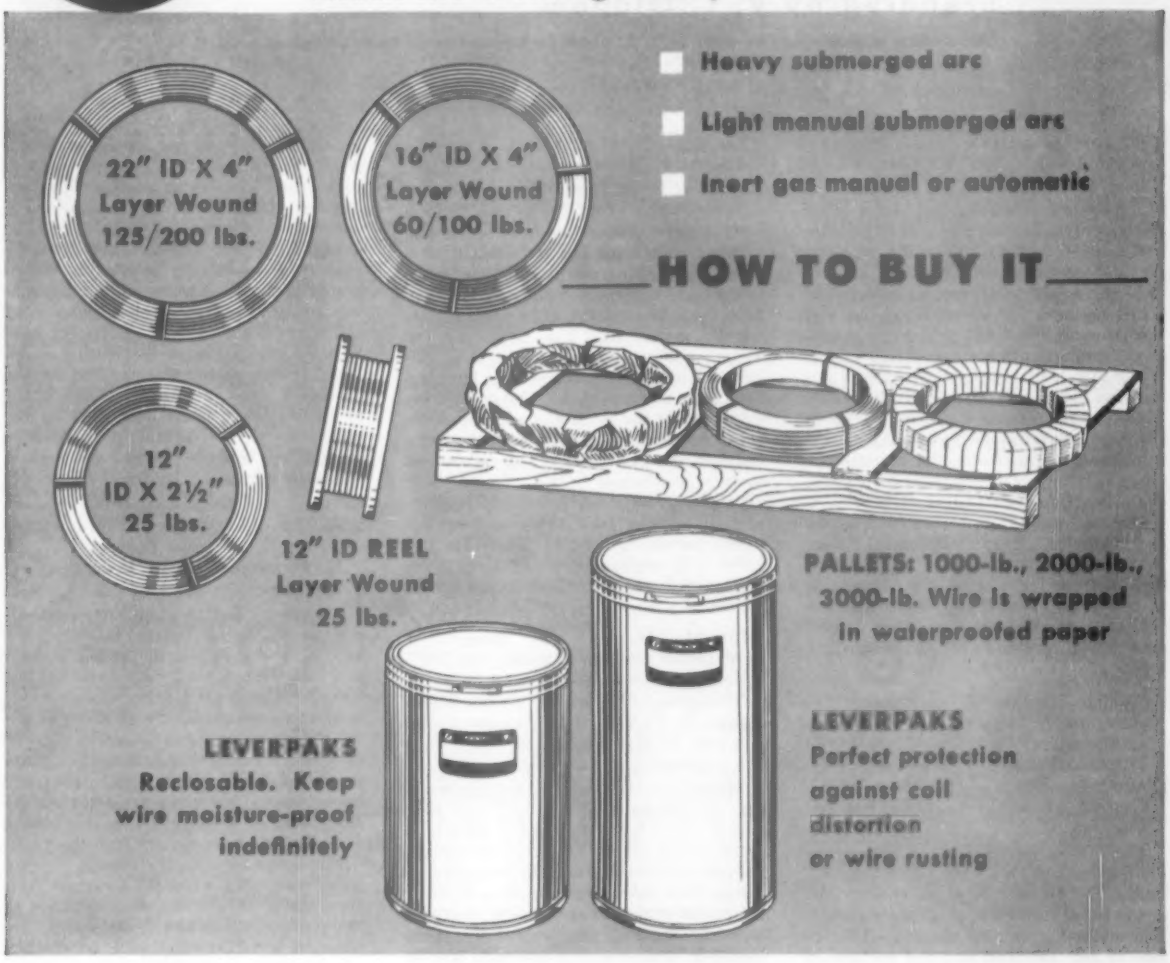
- ☐ Light manual submerged arc
- ☐ Inert gas manual or automatic



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ABSTRACTS OF CURRENT PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,701,290—APPARATUS FOR ELECTRIC WELDING—Kenneth V. Hart, Cleveland, Ohio.

This patented welding apparatus is for electric resistance welding and it includes a multipart clamping die and a movable die, and means for actuating the movable die. A variable pressure device is interposed between the actuating means and the movable die while a timer is operatively connected to such actuating means. A plurality of transformers are present and each has a secondary electrically connected to the pressing die and a part of the clamping die. Electrical energy storage means, comprising a capacitor and a gaseous discharge device, are connected in series with the primaries of the transformers while a control electrode is provided for the discharge device. Electrical connections are provided between the timer and the control electrode for energizing the discharge device to discharge the capacitor into the primaries of the transformers at a predetermined position of the actuating means.

2,701,483—METHOD OF SECURING INSERTS IN DUCTILE METAL MEMBERS BY PRESSURE WELDING—Henry James Foxon and Anthony Bagnold Sowter, Middlesex, England, assignors to the General Electric Co., Ltd., London, England.

These men have patented a pressure welding method for securing an irregularly shaped end of one metal member or element to a surrounding metal member. The method comprises cleaning the surface of one member and the surface of another member where both members are made from pressure weldable material and the cleaned surfaces of the members are positioned in facing relation and with the end of one member being in between the cleaned surfaces. A pressure is applied to a striplike welding area of the one member which encircles the end of the second member to bring the surfaces together and with the pressure being sufficient to reduce the combined cross section of the members to effect a pressure weld at the area and simultaneously therewith to create a flow of the metal displaced at the welding area and of the metal between the area and the element and around the end of such element to form an encircling mount therefor.

2,701,779—ALLOYED WELDING FLUXES—William M. Conn, Kansas City, Mo.

Conn's patented flux is for arc welding action and consists of approximately 82.5% mullite, 3% titanium dioxide, 8% ferromanganese, and 6.5% calcium fluoride.

2,701,833—HIGH FREQUENCY WELDER—Donald P. Worden, Rochester, N. Y., assignor to General Motors Corp., Detroit, Mich., a corporation of Delaware.

This patent is on an electric welding apparatus including a pair of rotatable electrode disks, connected to a suitable source of electrical current, separated axially from each other so that the disks are not electrically connected. The disks are cut away so as to form a peripheral groove adapted to receive a round tube having a butt seam to be welded. Means hold the tube against the electrodes with the seam to be welded in alignment with the space between the disks, and a plurality of flat surfaces are formed on cut-away portions of the electrode adjacent the portions thereof forming the groove and against which the tubing is held. These flat surfaces lie at angles of approximately 9, 30, 60 and 90 deg to the axis of the electrodes.

2,701,834—METHOD OF RESISTANCE WELDING OF LOW RESISTANCE NONFERROUS METALS AND APPARATUS THEREFOR—Charles R. Moore, Plainfield, N. J., assignor, by mesne assignments, to Alumanode Converters, Inc., a corporation of New Jersey.

Moore's patent relates to the spot welding of aluminum sheets and the like, which sheets have the normal aluminum oxide coating thereon. Two of such sheets are placed between liquid-cooled electrodes having high resistance contacts and having nonporous surfaces nonadherent to aluminum at welding temperatures. These electrode contacts are pressed against opposite faces of the sheets to provide electrical connections from electrode to electrode, and heating current is passed through the electrodes for a period only sufficiently to heat the contacts to welding temperatures and dissipate the oxide coatings in contact therewith to effect fusion and flow of metal between the contacts. The pressure is maintained while the electrodes and welded sheets cool below the fusion range.

2,701,852—LOW-FREQUENCY SEAM WELDER CONTROL—John R. Parson, Kenmore, and Hubert W. Van Ness, Buffalo, N. Y., assignors to Westinghouse Electric Corp., East Pittsburgh, Pa,. a corporation of Pennsylvania.

This patent relates to a frequency determining network for a low-frequency welder and covers the combination of first discharge device for initiating the supply of load current of one polarity when conductive, and a second discharge device connected to initiate the supply of load current of the opposite polarity when conductive. A flip-flop circuit is connected to the devices to permit one of the devices to conduct and to prevent the other of the devices from conducting. On-timing means and off-timing means are present and control means are actuated thereby to cause the one of the devices which is permitted to be conductive to conduct during an on-time. Other means are actuated by the on-timing means at the end of the timing cycle to cause means connected to the devices to permit the other of the devices to conduct, and to prevent the first of the devices from conducting.

2,702,333—ARC WELDING APPARATUS—Nelson E. Anderson, Berkeley Heights, N. J., assignor to Air Reduction Co., Inc., a corporation of New York.

Anderson's patent is on arc-spot-welding apparatus including an electrode holder supported for movement toward and away from a work piece to be welded. An electrode is gripped by the electrode holder and means bias the electrode holder in a direction away from the work. Means including an electromagnetic coupling, are providing for advancing the electrode holder against the biasing means when the electromagnet is energized so as to bring the electrode into contact with the work. Means responsive to the change in electrical conditions when the electrode contacts the work effects a deenergization of the electromagnet and renders the electrode holder advancing means inoperative.

2,702,846—NOBLE MONATOMIC GAS-SHIELDED MAGNETIC FIELD CONTROLLED ELECTRIC ARC WELDING PROCESS AND APPARATUS—Rudolph Thomas Breymeier, Niagara Falls, N. Y., assignor, by mesne assignments, to Union Carbide and Carbon Corp., a corporation of New York.

This patent related to the art of monatomic gas-shielded arc-metal working and the patented process comprises controlling the contour of the resulting worked metal by the step of subjecting the arc to the influence of a magnetic field derived from a variable strength source. This field is disposed in relatively fixed position substantially at right angles to the direction of the path of movement of the arc and substantially at right angles to the longitudinal axis of the arc. Hence the arc is constantly blown in the direction of the path for controlling the resulting contour of the so-worked metal.

NEWS of The Industry

Movie on Inert Arc Welding

A new motion picture, in full color with sound, has just been produced by Air Reduction on the inert-gas metal-arc process. "Nothing but the Best" is the title of this 20-min movie.

Typical applications of inert arc welding—production scenes shot in customers' plants—show manual, semi-automatic and completely mechanized equipment in use.

According to Airco, "Nothing but the Best" is ideally suited for showings to metal fabricators, business groups, technical schools and foremen's clubs. A print of the film may be borrowed from any Air Reduction office or by writing Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

•

NWSA Convention to Be Held in Chicago

The Eleventh Annual Convention of the National Welding Supply Assn. will be held at the Edgewater Beach Hotel, Chicago, Ill., on May 18, 19 and 20, 1955. An outstanding attendance is anticipated, including many representatives of known distributors of welding equipment outside of the United States, its possessions and Canada.

The opening Business Session is scheduled for 9:30 A.M., Wednesday, May 18th. Two other General Sessions will take place on Thursday, May 19th, and Friday, May 20th. Group luncheons are scheduled for Wednesday and Thursday at 12:30 P.M. The Sixth Annual Contact Booth Program will take place from 1:30 until 4:30 P.M. on Wednesday and Thursday.

A President's Reception is scheduled from 6:00 until 7:30 P.M. on Tuesday evening.

On Wednesday evening, the Associate Members will serve as hosts at another Reception from 6:00 until 7:30 P.M. in the Michigan Room at the Edgewater Beach Hotel.

On Thursday evening, the Association will hold a reception at 6:00 P.M. to be followed by the Annual Banquet and Dance.

The Business Session will be held on Friday morning.

The Convention Committee has given special attention to the development of the Ladies Program. An Informal Coffee Hour is scheduled from 10:00 until 11:30 A.M. on May 18th. This will be followed by a luncheon and fashion show at Marshall Field and Co.

On Thursday arrangements have been completed for the ladies to visit the Helene Rubenstein Salon at 10:00 A.M. and then have lunch at 12:30 P.M. at the Kungsholm Scandinavian Restaurant.

•

Linde Promotes Easterly and Hickling

Eugene Easterly has been appointed vice-president—distribution, and E. G. Hickling, vice-president—operations, of Linde Air Products Co., a division of Union Carbide and Carbon Corp., according to an announcement made recently by Thomas D. Cartledge, Linde's president.

Mr. Easterly joined Linde as a development engineer at Linde's Buffalo Laboratory in 1931. Since that time he has progressed through a number of positions with the company at various points throughout the country including Chicago, Pittsburgh, Indianapolis and Newark. He moved to the New York Office in 1941 and was appointed distribution manager for Linde in 1949. Mr. Easterly was born in Rochester, N. Y., and was graduated from the University of Michigan, in 1929, with a B.S. degree in Mechanical Engineering.

Mr. Hickling began his career with Linde in 1927 as an engineer at the company's laboratory in Buffalo. From there he was transferred to Linde's helium plant at Fort Worth and subsequently occupied positions in New York, Chicago, Pittsburgh, Trafford, Philadelphia and Detroit. During World War II he was engaged in handling priorities and other government matters for Linde. He became works manager for the company in 1949. Mr. Hickling was born in Chicago and was brought up in Idaho and Colorado. He was graduated in 1927 from the University of Michigan with a B.S. degree in Mechanical Engineering.

Agents for IIW Collections of Radiographs

The Balteau Electric Corp., New and Meadow St., Stamford, Conn., has been appointed agent for the IIW International Collection of Reference Radiographs of Welds (see page 81-s of the February 1955 issue of the *Welding Research Supplement*). This company will handle orders for both members and nonmembers of the International Institute of Welding.

The prices for the collections for sale in the United States are as follows:

Collections	*Transparent films*	*Paper copies*
63 radiographs	$57	$42
78 radiographs	71	51

Members of the American Welding Society associated with IIW are entitled to a discount of 10% on the above prices, including postage within the United States.

•

Esso Research

On Feb. 3, 1955 the Standard Oil Development Co. changed its name to Esso Research and Engineering Co. The change is solely one of company name. All personnel and mail addresses remain unaffected.

•

Anderson Promoted

H. E. Martin, president of Metal & Thermit Corp., New York, N. Y., has announced the appointment of E. E. Anderson to the position of vice-president.

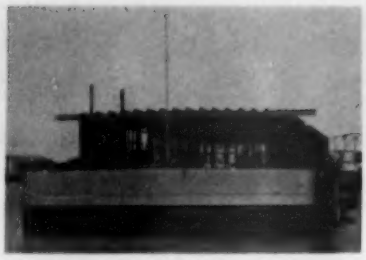
Mr. Anderson has been with Metal & Thermit for more than forty years and was assigned to its South San Francisco plant in 1920. Since 1940 he has headed the company's operations in the western states and will continue to act as its top management executive on the Pacific Coast. He is a director of the Manufacturers Assn. of San Mateo County and has been a leading figure for a number of years in the area's industrial group. He is a member of the American Welding Society.

All-Welded Dredge Hulls

Engineers of Oyster Shell Products Corp. aimed at the twin benefits of lower-cost maintenance and improved operating efficiency in specifying material for the hull of two vessels recently constructed at the corporation's shipyard, Morgan City, La.

The hulls of both the *Captain Charlie*, a hydraulic dredge used in dredging oyster shells, and the *Smith Alpha*, a tugboat, are fabricated of corrosion-resistant wrought iron plate. More than 70 tons of this plate, $^5/_{16}$ to 2 in. thick, are in the hull and keel applications.

Wrought iron's ability to resist the aggressive action of corrosive water is expected to reduce the frequency of repairs and thus result in less out-of-service time for both vessels.



Wrought iron dredgehull of all-welded construction

The hull of the dredge *Captain Charlie* is 136 ft by 42 ft by 9 ft. It is one of the largest hulls built in the Morgan City area. Bulkheads and deckplates are fabricated of $^3/_8$-in. wrought iron plate, with sides and bottom $^1/_2$-in. thick. A 1200-hp General Motors Diesel is used to power the dredging and processing equipment of the dredge.

The tugboat *Smith Alpha* is 88 ft long with a 25-ft beam and a depth of 10 ft. She is powered by a 550-hp steam engine The bulkheads and hull are of $^3/_8$-, $^7/_{16}$- and $^1/_2$-in. plate. The deck is $^3/_8$-in. checkered wrought iron with keel and stem built of 2- by 8-in. plate.

Both workboats are of sturdy all-welded construction.

AMONG THE 183 ATTENDEES AT THE MIDWEST WELDING CONFERENCE

They came from throughout the country to attend the two-day Midwest Welding Conference in Chicago. Shown here are Orville T. Barnett, supervisor of welding research at Armour Research Foundation of Illinois Institute of Technology (*left*) and Amel R. Meyer, chairman of the Chicago Section of the AWS

These smiling faces belong (*left to right*) to H. C. Boardman, director of research, Chicago Bridge and Iron Co.; William Spraragen, director of Welding Research Council, and William H. Munse, research associate professor of civil engineering at the University of Illinois. Conference took place on February 8th and 9th

Carl E. Hartbower, chief of the Welding Section at Watertown Arsenal, inspects the interesting Armour Research Foundation display at the Conference. ARF was the host organization, together with the Chicago Section

Barnett is pictured here with two other speakers: E. C. Osborne (*center*), quality control manager, Caterpillar Tractor Co., and A. E. Gander (*right*), process representative, Air Reduction Sales Co

STAINLESS STEEL

...fights corrosion...solves many piping problems

● Stainless steel piping, using TUBE-TURN* Stainless Steel Welding Fittings, can provide long, safe service where corrosive gases or fluids are handled. Likewise, stainless steel systems are superior where temperature extremes are encountered, for handling dangerous materials safely, for preventing contamination.

Tube Turns offers a *complete line* of Stainless Steel Welding Fittings in three analyses: AISI Type 304, Type 347, and Type 316; and in four schedules: 5S and 10S (thin wall), and 40S and 80S (heavy wall). For the *right* stainless steel welding fittings, and for help in proper application, get in touch with your Tube Turns' Distributor. You'll find one in every principal city.

TUBE-TURN Welding Fittings and Flanges are made in U.S.A. They meet all U.S. piping code specifications

TUBE TURNS LOUISVILLE 1, KENTUCKY

A Division of National Cylinder Gas Company

DISTRICT OFFICES: New York • Philadelphia • Pittsburgh • Cleveland • Detroit • Chicago • Denver • Los Angeles San Francisco • Seattle • Atlanta • Tulsa • Houston • Dallas • Midland, Texas

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STAINLESS DATA

How you get *extra service* from TUBE-TURN* Stainless Steel Welding Fittings

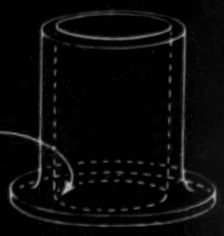
EXTRA-VALUE FEATURES AT NO EXTRA COST

UNIFORM WALL ASSURES UNIFORM STRENGTH

All TUBE TURN Welding Elbows meet ASA B16.9 and MSS SP43 Standards on minimum wall thickness of 87½% of nominal thickness particularly important on thin wall welding elbows. Many elbows on the market are as much as 30% to 40% below nominal thickness at this point of greatest wear. Wall thickness is likewise uniform on the inside radius no "bunching up" of metal.

MATCHES PIPE BURSTING STRENGTH

Welding Tees are adequately reinforced. Along with other TUBE TURN Welding Fittings their strength matches the calculated bursting strength of the pipe.



NO CORROSION POCKETS

TUBE TURN Lap Joint Stub Ends have a square inside corner which eliminates a "corrosion pocket" and a proper fillet radius which assures strength under flexing and vibration.

CHECK THESE FEATURES
Only TUBE TURNS offers them all

- Fittings meet standard chemistry specifications
- Minimum wall thickness of elbows 87½% of nominal
- Fittings meet minimum calculated bursting pressure of matching pipe
- Qualified welders and procedures used where welding is required
- Each fitting properly solution heat treated
- Each fitting passivated
- Other special grades of stainless steel, and all other alloys available

All these extra value features available to you at no extra cost.

MEET ALL CODES

TUBE-TURN Stainless Steel Welding Fittings meet all specifications: ASTM A312 (for material); MSS SP43 and ASA B16.9 (for dimensions); and MSS SP25 (marking procedure).

IMPORTANT DATA...

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224 East Broadway, Louisville 1, Kentucky
Please send STAINLESS STEEL "WHY AND WHERE" book.

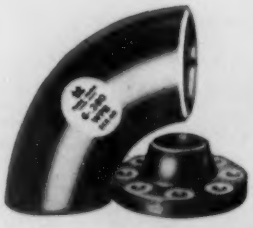
Company Name _____

Company Address _____

City _____ *Zone* _____ *State* _____

Your Name _____

Position _____



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New York	Los Angeles
Philadelphia	San Francisco
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Cleveland	Atlanta
Chicago	Tulsa
Detroit	Houston
Denver	Dallas

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TUBE TURNS

A DIVISION OF NATIONAL CYLINDER GAS COMPANY
LOUISVILLE 1, KENTUCKY

Nelson Appoints Butterfield

Paul H. Butterfield, who has occupied key positions with the Nelson Stud Welding organization in various parts of the country since 1944, has been named specifications specialist for the Nelson Stud Welding Division of Gregory Industries, Inc., with headquarters at 206 E. 26th St., New York City.

•

K-G Distributor

The K-G Equipment Co., Inc., of Allentown, Pa., announce the appointment of Welders Service & Sales Co., 2164 Spring Grove Ave., Cincinnati, Ohio, as their distributor. The distributor will handle K-G welding and cutting torches, regulators and related equipment.

•

McKay Canadian Distributor

Williams and Wilson, Ltd., have been appointed distributors for McKay electrodes. The company's headquarters are in Montreal and it maintains branch offices in Windsor, Toronto and Quebec. They carry a complete line of McKay electrodes. For additional data, write Williams and Wilson, Ltd., P. O. Box 6117, Montreal, Ont., Canada.

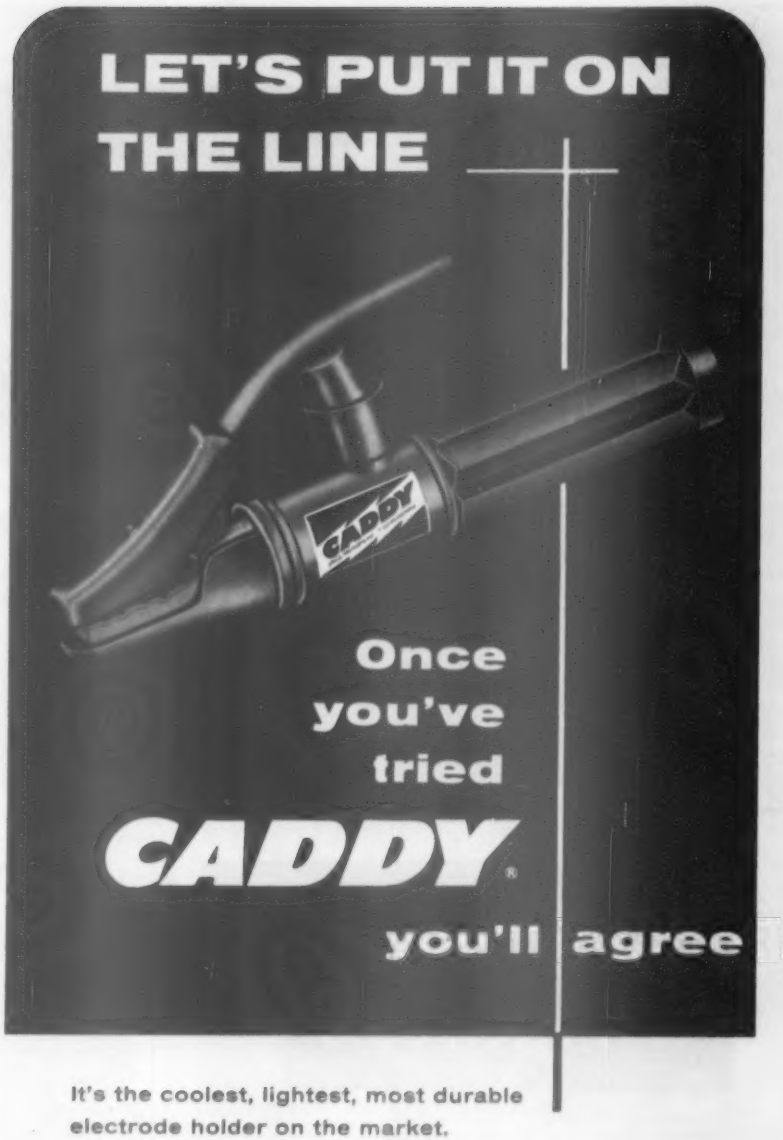
•

Structural Steel Business Good

At a luncheon meeting held at the Uptown Club, New York City, on February 18th, the American Institute of Steel Construction provided a vehicle for people prominent in the structural steel industry and interested engineering editors to meet the new President, Earle V. Grover. Mr. Grover is also President of the Apex Steel Corp., Ltd., of Los Angeles, and the first West Coast member to hold this office.

Mr. Grover indicated that at a recent meeting of the 25 Directors of the Institute, representing all parts of the country, an optimistic picture was painted for the structural steel industry as all but one predicted as good or better business in 1955 as in 1954. Several years ago the structural steel industry suffered because it was difficult to get steel. The situation has changed and even buildings and structures which were originally contemplated to be built of other materials are being redesigned to use steel.

Mr. Grover was particularly optimistic for the California area. He also indicated that welding was playing an important part in construction of steel structures in the California area.



It's the coolest, lightest, most durable electrode holder on the market.

For further information on the CADDY TEST INSTALLATION PROGRAM in your plant—write

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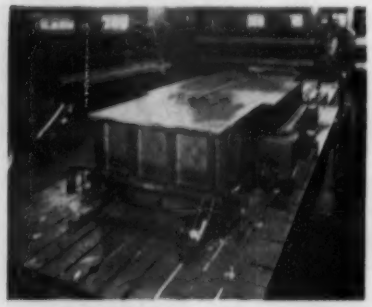
Welded Bedplate

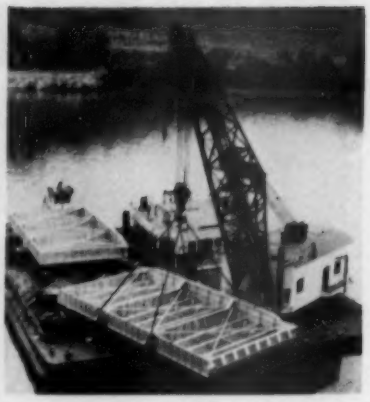
This 70-ton bedplate for a 5,000,000-lb Baldwin universal testing machine, to be the largest in the world, was recently planed on the largest planer in Baldwin-Lima-Hamilton machine shop at Eddystone, Pa.

The testing machine, to be installed at Lehigh University later this year, will have a maximum clear space for test specimens 40 ft high and 10 ft between columns.

Unlike bedplates for two former machines of this capacity but of less height, a weldment was specified. It measures 23 ft 10 in. long, 11 ft 3 in. wide and 4 ft thick. The structure was fabricated, X-rayed and stress-relieved in the company's weld shop.



Welded Miter Gate



New 98-ton miter gate for the upstream end of the main lock of Locks No. 26 on the Mississippi River at Alton, Ill., near St. Louis, is lifted aboard tandem barges at the Dravo Corporation shipyard, Pittsburgh. Each gate leaf, fabricated of welded steel, is $60^1/_2$ ft long by approximately 30 ft high. The gate was constructed by Dravo for the St. Louis District, Army Corps of Engineers. Two barges lashed together delivered the gate to St. Louis.

Diversey Appoints Bennett

W. A. Noyes, Vice-President in charge of Sales for the Diversey Corp., Chicago, recently announced the appointment of Myron T. Bennett to Promotional Manager of the Metal Industries Department.

Mr. Bennett previously was General Manager of the Spec-Kem Co., a division of the Diversey Corp., supplying special chemical compounds to government agencies.

P&H Distributor

Announcement of a new distributor in the Cleveland and Ashtabula, Ohio, areas has recently been made by the P&H Welding Division of the Harnischfeger Corp., Milwaukee, Wis. The new distributor is Welding and Cutting Supply Co., 2401 Carnegie Ave., Cleveland 15, Ohio. The company also maintains a branch at Ashtabula under the name of Weld-Cut, Inc., 3224 Station Ave.

Welding and Cutting Supply was established in 1931. Officers are Manuel W. Powar, president; Samuel Cholfin, vice-president, Minda C. Powar, treasurer; and Robert Cholfin, sales manager. Paul Cholfin is manager of the Ashtabula branch while Alex Doyle is sales manager.

Poor fit-up a problem?

Try Westinghouse

FP-2 ELECTRODES

We're so sure our electrodes will do a better welding job for you, we're prepared, we're anxious to send you free samples. FP-2 electrodes are excellent where fit-up is poor—best used on auto parts, boats, gear guards, truck bodies, structural steel, machinery parts.

SEND TODAY

Drop us a note on your company stationery. Free electrode samples will be sent to you. Also ask for the full-line folder on Westinghouse electrodes. J-21871

Westinghouse Electric Corporation
Welding Department
P. O. Box 868, Pittsburgh 30, Pa.

YOU CAN BE SURE...IF IT'S Westinghouse

WELDING ENGINEER

To assume responsibility for all flash and resistance welding problems. Duties will include: development of new techniques, control of production procedures and methods, supervision of designing welding dies, tools, and fixtures, working with production foremen and manufacturing engineers on welding processes and consulting with customers to establish welding specifications and standards of performance.

We require a man with at least five years experience in establishing flash welding procedures and schedules. Experience in automatic submerged arc, manual and inert gas welding desirable. He should have expert manufacturing knowledge of flash welding of bar size material up to 30 square inches in carbon, alloy, and stainless steels, and be familiar with U.S.A.F. certification procedures.

His experience should include the supervision of the design of welding tools, dies and fixtures, the solving of shop welding problems and improving procedures, the establishing of practical quality control procedures, and a proven record in meeting manufacturing requirements and time schedules. Ability to work with both sales and manufacturing personnel essential.

The company is a nationally known 75 year old steel fabricating manufacturer serving diversified industrial needs.

Applicants should submit complete resumes to Box V-319, The Welding Journal.

Get the BEST for LESS
Get
"ANTI-BORAX" FLUXES
Fully Guaranteed
SAFE—NON-TOXIC

No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux
No. 4 "Braz-Cast" Flux for bronze welding cast iron
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Send for complete Folder

Mfg. by
ANTI-BORAX COMPOUND CO. INC.
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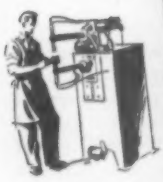
Magnetic? OR Electronic? WELDER CONTROL — WHICH WILL DO YOUR JOB BEST?

Square D makes them all... for simplest or most exacting applications!

Magnetic

for General Purpose Machines

For applications requiring widely varying welding conditions, normal welding speeds and maximum simplicity.

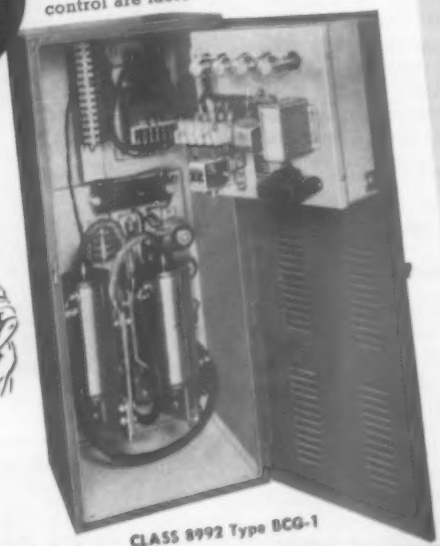


CLASS 8992 Type BBG-1

Electronic

for High Speed Welding

For production line (gun or stationary) welders and other applications where high speed, high currents or dual gun control are factors.



CLASS 8992 Type BCG-1

Electronic (SYNCHRONOUS)

for Precision Welding

For welding aluminum, other non-ferrous and ferrous metals requiring precision weld times; stepless heat control; slope or taper control.

CLASS 8992 Type BDG-1

You'll find your nearby **Square D Field Engineer** *a source of sound counsel in selecting the welder control best suited to your application.*

SQUARE D COMPANY

PERSONNEL

Smith Promoted

At a recent meeting of the board of Directors of the Nooter Corp., St. Louis, Philip H. Smith was elected to the office of Vice-President–Sales Engineer. Mr. Smith is a member of the AMERICAN WELDING SOCIETY.

•

H. M. Meyer Relocates

Herbert M. Meyer, research metallurgist for Armour Research Foundation since 1951, has accepted a position with Watertown Arsenal Laboratory as chief of the metals research branch. Dr. Meyer worked in Chicago on the physical metallurgy of welding in titanium alloys and is the author of several papers which have appeared in THE WELDING JOURNAL.

•

Roth Made Regional Manager

Jerome M. Roth, 321 Bloomfield, Caldwell, N. J., has been appointed Regional Manager for All-State Welding Alloys Co., Inc., to cover the states of New Jersey, Delaware and Maryland, and the contiguous areas of Pennsylvania, Virginia and West Virginia. Announcement of his appointment was made by T. D. Nast, president, at the Company's offices, White Plains, N. Y.

Mr. Roth is a member of the AMERICAN WELDING SOCIETY.

Jerome M. Roth

Biers Honored by Spanish Institute

Howard Biers, consulting engineer, Union Carbide and Carbon Corp., has been designated an Honorary Member of the Institute of Welding of Spain. Mr. Biers is president of the International Institute of Welding and is chairman of the American Council of the IIW.

•

A. F. Davis Receives Appointment

A. F. Davis, vice-president and secretary of the Lincoln Electric Co., has been called to serve as head of the sponsoring committee of the Future Farmers of America Foundation. This group represents some 230 businesses and industries interested in aiding young men become established as competent, independent farmers as well as leaders in their communities.

The Sponsoring Committee which Mr. Davis heads, provides funds to the Future Farmers of America Foundation. The Foundation was established in 1944 to permit business, industry, civic groups and individuals to cooperate in the activities of the Future Farmers of America. This organization, now numbering some 375,000 members is the national organization of, by and for boys studying vocational agriculture in public high schools under the provisions of the National Vocational Education Acts.

•

Adams Honored

A College of Engineering was established at New York University one hundred years ago. At the Midwinter Convocation to celebrate this centennial of engineering, one hundred alumni were honored by having conferred upon them a "Certificate of Distinction" bearing the citation, "valued alumnus whose professional achievement and services to the common good in our judgement are of distinct credit to himself and to this Institution in which he received part of his education."

Among these alumni was Ludwig Adams, Vice-Chairman of the Pittsburgh Section of the AMERICAN WELDING SOCIETY.

Strand Wins Diploma

Dean E. Strand, 427 Dwight St., Kewanee, Ill., has been awarded a diploma in Industrial Management by LaSalle Extension of the University of Chicago after a year's study in his spare time. Strand is a graduate of Kewanee High School and Naval Shipfitters School, and a veteran of World War II and Korea. He is a member of Boilermakers Union and AMERICAN WELDING SOCIETY (Peoria Section).

•

Blodgett Made General Sales Manager

E. R. Walsh III, vice-president in charge of sales of Alloy Rods Co., announced recently the appointment of F. L. Blodgett to the position of general sales manager. Mr. Blodgett joined the company in 1950 as sales manager of the Hardfacing and Tool Steel Division, later advancing to the post of assistant general sales manager. Alloy Rods Co. is located at Lincoln Highway West, York, Pa.

F. L. Blodgett

VISIT THE
WELDING SHOW
MUNICIPAL AUD.
Kansas City, June 8–10

For 50 Years... Sold the World Over

FIBRE-METAL HELMETS

THEY'VE HAD TO BE GOOD!

● The name FIBRE-METAL stands for highest quality... *quality* preeminent in the field of welding... based on broadest experience and continuing research to produce the kind of equipment that gives maximum protection to the welder... along with the comfort and "work ability" that enable him to produce more work per day.

FIBRE-METAL HELMETS: *First with Fiberglas!**

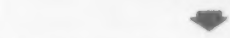
No. 600-3-C
No. 602-3-C

No. 604-3-C
No. 606-3-C

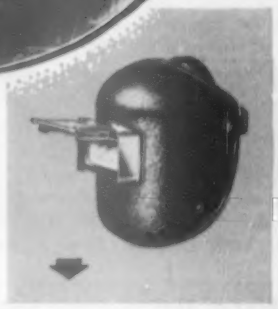
No. 700-3-C
No. 702-3-C

Inside view showing INNER BIB of "Series 400" Helmets for extra protection to welder's neck from flashes and reflected glare.

*OWENS-CORNING TRADE MARK



No. 400-3-C with #1130—Plastic Glass Holder
No. 402-3-C with #1085—Insulated Steel Glass Holder



No. 404-3-C with #1136—Plastic Lift-Front Glass Holder
No. 406-3-C with #1096—Insulated Dowmetal Lift-Front Glass Holder

NEW
"Series 400" Helmets

The smaller size and light weight of the Fibre-Metal Series 400 Helmets make them ideal for close quarters. They feature Fibre-Metal's superior Fiberglas* compression-molded shells, Beaded edges for strength and safety, Wide Range Headsize Adjustment, New 4-Position Helmet Stop, and provide four popular glass holder styles. Adjustable friction joints hold helmet in any position!

HELMET FEATURES:

LIGHT WEIGHT • EXCEPTIONAL STRENGTH • MOISTUREPROOF NON-WARPING • HEAT RESISTANT (SELF EXTINGUISHING) EASILY STERILIZED

OVER 30 TYPES TO MEET YOUR NEEDS

When buying any welding equipment... always ask for a FIBRE-METAL product!

FIBRE-METAL

WORKER SAFETY PAYS DIVIDENDS

THE WORLD'S LARGEST MANUFACTURER OF QUALITY PRODUCTS FOR WELDERS

Sold Everywhere thru leading Distributors and Dealers

THE FIBRE-METAL PRODUCTS CO.
CHESTER, PENNA.

OBITUARY

R. B. Reilly

R. B. Reilly, southwestern regional engineer of American Institute of Steel Construction, died February 19th, in the crash of an airliner near Albuquerque, N. Mex. He was 51 years old.

He had been district engineer of AISC, with headquarters in Dallas, Tex., since 1948, becoming regional engineer in January 1955.

Before joining AISC, Mr. Reilly was with Powell & Powell of Dallas, Muskogee Iron Works, Muskogee, Okla., and Austin Brothers Structural Steel Co., Dallas. He was a graduate of Texas A&M College in 1926.

Mr. Reilly was a member of the American Society of Civil Engineers, the Texas Society of Professional Engineers and the AMERICAN WELDING SOCIETY. He is survived by his wife and two children.

Raymond E. Powell

Raymond E. Powell, metal joining engineer at the Western Electric Kearny (N. J.) Works, died Dec. 10, 1954 in New York Hospital, New York City, following a brief illness and a minor operation. He was 63 years of age.

Mr. Powell was an organizer and past-chairman of the New Jersey Section of the AMERICAN WELDING SOCIETY. He had been a member of the Society for the past 28 years and was for 15 years a member of its program committee for the annual meetings.

A specialist on welding, brazing and soldering, Mr. Powell held 18 patents along these and allied lines and was the author of a number of articles on welding which have appeared in technical publications. He was a graduate of the University of Missouri with a B.S. degree in electrical engineering. He had been with the Western Electric Co. since 1922.

Mr. Powell's home was at 625 Lenox Ave., Westfield, N. J. He is survived by his wife, Mrs. Marie C. Powell, a daughter, Mrs. Patricia Zirklw, and three grandchildren.

David Shenck Jacobus

Dr. David Shenck Jacobus, advisory engineer of the Babcock & Wilcox Co. from 1906 until his retirement in 1941, died February 11th, in his ninety-fourth year, after a long, brilliant and highly productive career as a teacher, scientist and engineer. He was a past-president (1916) of the American Society of Mechanical Engineers and, as a member and honorary member, was affiliated with that society for 66 years. He was a past-president of the American Society of Refrigerating Engineers (1906) and the AMERICAN WELDING SOCIETY (1934). He was prominent in nearly a dozen technical engineering and learned societies.

He served with distinction as a member of the faculty of Stevens Institute of Technology from the year of his graduation (1884) until he joined the Babcock & Wilcox Co., at which time he received the degree of Doctor of Engineering from Stevens. With his qualities of leadership, technical knowledge and practical skill, his wide influence in engineering continued as a consultant after his retirement. He was granted 188 patents pertaining to boilers, furnaces, superheaters, purifying steam, forced circulation and other power plant apparatus.

One of his most important activities was his work on the Boiler Code Committee of the ASME which led to the formulation of boiler codes and standards for the design, construction and inspection of boilers and unfired pressure vessels.

He received international as well as national recognition for his work in the field of steam boiler design. He contributed many authoritative papers in that and allied fields which have been a source of inspiration to countless engineers and students. He was awarded the Morehead Medal of the International Acetylene Assn. in 1935, for outstanding leadership in formulating the codes and procedures which helped to make fusion welding acceptable. One of the high engineering honors, the Miller Medal, was conferred upon him by the AMERICAN WELDING SOCIETY in 1943.

At the 150th anniversary of the founding of the American patent system, the National Association of Manufacturers cited Doctor Jacobus as "a modern pioneer" in his field—"men who through their pioneering achievements on the frontiers of American Industry have made significant contributions to the creating of new jobs, new industries, new goods and services." It was recalled that the results of his inventions "have aided reduction in cost of electricity in spite of the advances in fuels and labor, lightening household burdens and increasing employment."

Doctor Jacobus was born at Ridgefield, N. J., Jan. 20, 1862, and resided in Montclair, N. J.

CHECK THESE EXCLUSIVE ADVANTAGES of the NEW

HI-AMP HOLDER

-and You'll Wonder Why You're Not Using them Now!

- Spring completely enclosed and insulated. Cannot be knocked or shorted out.
- Spring adjustment screw for ease of replacement and adjustment to rod size.
- Handle cannot absorb moisture-withstands higher temperatures.
- Tip Insulator reversible for longer service life.
- Low Trigger for ease of rod-relief-cuts down operator fatigue.
- Slender rod gripping tongs to get in tight places.

Sold only through Welding Supply Distributors in the U. S. and Canada.

WAGNER MFG. CO.
350 W. 1st SOUTH ST.
JACKSON, MISSOURI

Weld with Wagner

you can be one of the lucky weldors to get a

"GOLD ROD"

. . . share $300 in awards

COMMEMORATING EUTECTIC'S 15TH YEAR OF "GOLDEN" SAVINGS FOR AMERICAN INDUSTRY AND FIRST 50 YEARS OF RESEARCH

There's no contest to enter! Nothing to write! Between April 1st and November 1st, 1955, five weldors will find a special "Gold" rod or electrode in their shipments of new, 1955 Eutectic "Low Temperature Welding Alloys." One represents the 1 billionth "rod" produced by Eutectic during its first fifteen years. The weldor who returns it to his Eutectic District Engineer will receive a $100 award.

The four other "Gold" rods symbolize Eutectic's 15th Anniversary and first 50 years of research. The weldors who return these will each receive a $50 award.

It's as simple as that. Just be on the watch for a "Gold" rod in your shipments of EutecRods and EutecTrodes.

MAKING WELDING EASIER AND MORE PROFITABLE THROUGH RESEARCH

15 years of relentless research have helped Eutectic "Low Temperature Welding Alloys" gain the preference of a rapidly increasing number of weldors in 87,000 American industries. Each year, Eutectic research has introduced new products for "Better, Faster, Cheaper" welding. Now, a new "15th Anniversary" laboratory in Flushing, N. Y., and additional research centers in Europe will assure continued advances in the fight against an important cause of weld failure: HIGH HEAT!

To keep pace with the increasing demand for Eutectic "Low Temperature Welding Alloys," a 1,000-rod-per-minute extrusion press and baking oven has been installed in Eutectic's Flushing plant. As on all five Eutectic production lines, the speed of this equipment is secondary to its ability to meet the rigid quality controls that maintain every Eutectic product at the most exacting specifications.

EUTECTIC DISTRICT ENGINEERS PROVIDE UNIQUE "SHOP-TO-SHOP" SERVICE

The more than 350 District Engineers show . . . so weldors can know . . . how to get every advantage of "Low Heat Input" metal joining. On every call, the Eutectic District Engineer brings in his "kit" the full resources of Eutectic research, new alloy developments, and the vast experience that he and all his fellow District Engineers have amassed over the years.

One of the many products introduced by Eutectic District Engineers during 1954 was EutecTrode 1850 — the all-purpose, highest tensile copper alloy for joining and overlaying dissimilar metals. During 1955, they'll introduce other and equally superior new "Low Temp" EutecRods and "Low Amp" EutecTrodes. Watch for these new sources of savings.

50th YEAR OF WELDGINEERING

J. P. H. Wasserman first saw the phenomenon of surface alloying and adapted it into a new welding process in 1905. Rene D. Wasserman perfected the process, and, in 1940, founded Eutectic Welding Alloys Corporation, in New York. Eutectic is now the inventor, patentee and sole manufacturer of Eutectic "Low Temperature Welding Alloys"® that minimize or completely eliminate the dangers of high heat fusion welding — warping, distortion, stress and embrittlement of base metals. Today, after 50 years of pioneering and Weldgineering, Eutectic is your guarantee of a profitable solution for most welding problems . . . your one source of "Low Heat Input" metal joining techniques.

J. P. H. Wasserman

R. D. Wasserman

FREE 15th ANNIVERSARY DIRECTOROD GUIDE

There is no substitute for Eutectic "Low Temperature Welding Alloys" . . . no "produced-for-a-price" welding material can ever provide Eutectic results. To help you select the EutecRod or EutecTrode that will give you the largest savings per job, write today for your free copy of the new, 32-page 15th Anniversary Directo-Rod Guide to "Better, Faster, Cheaper Welding." *Just ask for TIS 1340.*

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Current Welding Literature

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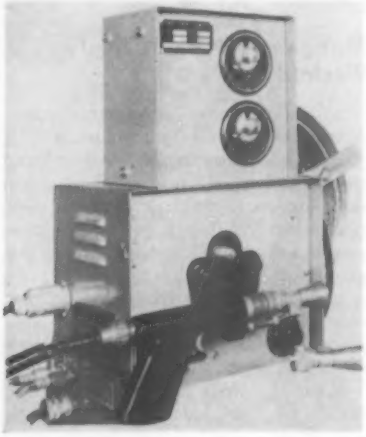
NEW PRODUCTS

Welding Control

An automatic spot and tack welding control for use with all Linde SWM-2 Sigma units is now in production by the Glenn Co., Oakland, Calif. This control provides an automatically timed cycle for the welding operation. The operator merely places gun against the workpiece and pulls trigger. The Glenn



control turns on power, rod feed, gas and water for an adjustable preset welding interval. Rod feed is shut off at an adjustable period in advance of power cutoff to burn back excess rod.

Literature, data and prices may be obtained by writing to Glenn Co., 3134 E. 10th St., Oakland 1, Calif., or 10222 South Avenue N, Chicago 17, Ill.

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Industrial Curtains

Duratex Utility Curtains, manufactured by Duracote Corp., Ravenna, Ohio, consist of a fabric base woven of Fiberglas or nylon yarn coated with synthetic plastic resins. According to the manufacturer, Duratex Utility Fabrics do not support combustion and are widely used for welding curtains and as electrical insulating blankets for the protection of personnel and equipment during maintenance and repairs.

More detailed information on Duratex industrial curtains and partitions and dividing curtains is available from Duracote Corp., Ravenna, Ohio.

Low-Hydrogen Electrode

A new low-hydrogen electrode, with powdered metal added to the coating, has been announced by General Electric Co.'s Welding Department, York, Pa.

Designated Strikeasy LH-1, the new electrode provides faster and easier operation than conventional low-hydrogen electrodes, with excellent x-ray properties of weldments, according to company engineers.

The new Strikeasy LH-1 is usable on alloy and mild steels, and meets the requirements of the A-6016 classification in as-welded condition, and A-7016 class in the stress-relieved condition.

•

G-E A-C Welder

A new general purpose a-c welder, for job shops and light industrial applications, has been announced by the General Electric Co.'s Welding Department, York, Pa.

Covering a current range of 25 to 295 amp, the new low-priced welder is ideal for maintenance work, tack welding at high currents, and steady welding at moderate currents, according to G-E engineers. The welder provides a 50% duty cycle in the normal welding range of 200 amp, with somewhat lower duty cycles when higher settings are used. It has a low-range open-circuit voltage of 75 v, and a 65-v OCV is supplied at high current settings.

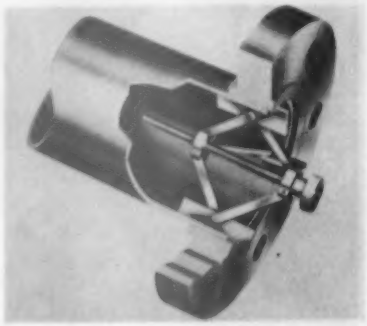
Utilizing the moving primary coil design, the G-E welder is supposed to provide pin-point accuracy of current settings and resettings. The welder also includes a dual position range switch, fingertip current adjustment, and bolt-type output terminals.

Type WK29A, the general purpose and job shop model, includes a 230-v primary circuit, with steel-tired castors as standard equipment.

For heavier applications, G-E makes a separate type (WK29L), which includes a 230–460 reconnectable primary circuit. As optional equipment, G-E provides an "arc performance package" including arc stabilizing capacitors and G-E's automatic hot start. According to the manufacturers, these features provide easy starting and stable operation throughout the entire current range. Castors and power factor correction capacitors are also available on type WK29L.

Alignment Tool

A new self-centering flange aligning tool designed to accommodate any pipe size from 3 to 12 in. is now being marketed by the Contour Marker Corp., 1843 Compton Blvd., Compton, Calif.



The new device is slipped into the pipe and expanded to center itself snugly against the inside diameter, with the stepped shoulder members against the pipe's end face. Projecting shoulders are thereby automatically aligned with the pipe axis and, when the flange is held in position against these projecting shoulders, the flange can be quickly welded in perfect alignment without the time consuming methods ordinarily necessary.

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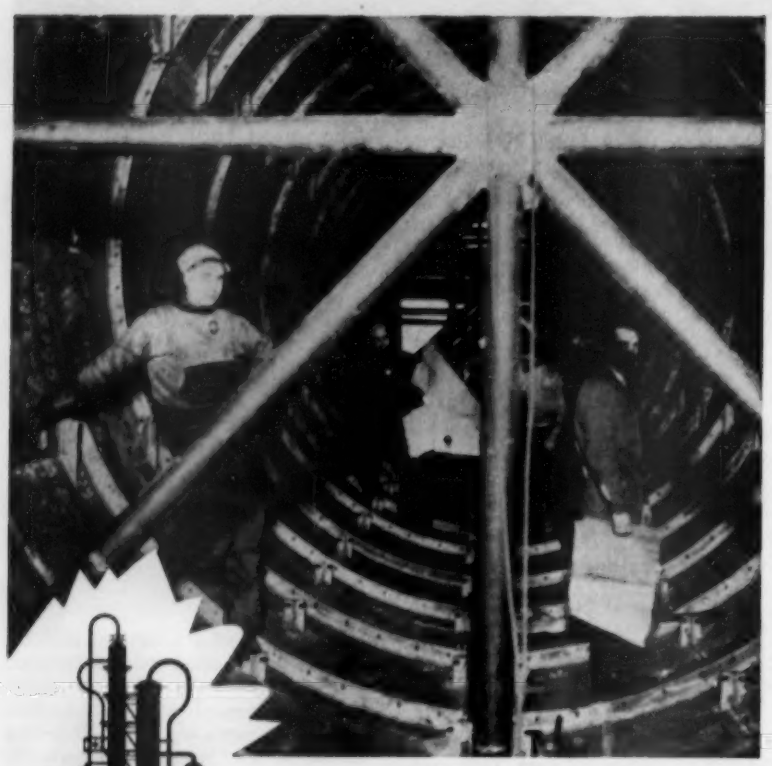
Soapstone Holder

A soapstone holder that protects the marking material from breaking and from becoming mislaid and enables welders to use short ends is available from Atlas Welding Accessories Co., 707 E. Lewiston, Ferndale 20, Mich.

This holder is rigid metal, has a spring clip for carrying it in the pocket and has a button slide in the back so the soapstone can be readily expelled as it wears down.

ARCOS FOR FINEST QUALITY WELDS



Acids get tamed in towers of **welded** clad steel

With no weak spots to corrode, Reactors and Towers of welded 410 clad steels can stay "on stream" constantly . . . give longer service life with reduced maintenance.

However, the success of welded equipment that handles corrosive acids depends on sound corrosion resistant weld metal. Arcos Stainless weld metal is a match for *any* job you may have. Even when other factors are involved—extreme heat or pressure—there's an Arcos Stainless Electrode to satisfy the most critical requirements. What's more, if you're faced with an unusual fabrication problem, Arcos technical assistance provides an additional bonus of help. Arcos Corporation, 1500 South 50th Street, Philadelphia 43, Pennsylvania.

WELD WITH ARCOS

STAINLESS RODS AND ELECTRODES

Brazing Flux

A special flux for silver alloy brazing of stainless, chromium heat-resisting alloys, chromium and tungsten carbides is being offered by Handy & Harman, New York, N. Y. Called Special Handy Flux Type B-1, the new flux is designed to reduce oxides of the refractory metals while protecting the underlying metal from further oxidation during brazing.

An important feature of the new flux is its ability to withstand heating at 1400–1600° F for short times and to increase its life at lower brazing temperatures.

Further information about Type B-1 Flux can be obtained from Handy & Harman, 82 Fulton St., New York 38, N. Y.

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Manganese-Nickel Steel Electrodes

According to its manufacturer, the Manganal Flo-Kote electrode, a 11–13½% manganese-nickel steel welding electrode, has all the ease of handling associated with mild or stainless steel electrodes; yet it is a genuine manganese-nickel steel electrode with all the alloys in the wire, not in the coating. It is used not only in welding manganese steel to manganese steel, but also manganese steel to mild or high-carbon steels.

Write for free literature to Stulz-Sickles Co., 134 Lafayette St., Newark 5, N. J.

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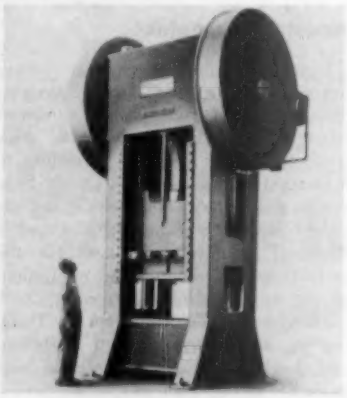
Single-Point Presses

Continuing its expansion in the heavy press field, Cleveland Crane & Engineering Co., Wickliffe, Ohio, is now introducing a line of twin-geared Steelweld Single-Point Presses of the straight-side tie-rod type.

The machines, which are mechanically powered, are of the welded steel construction and incorporate the latest



advances in design for safety and dependability.

Sizes developed range from 150 to 500 tons and have bolster areas of 30 x 36 in. to 42 x 48 in. Operating speeds are from 10 to 20 strokes per minute.

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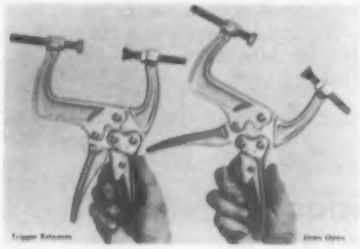
Toggle Clamps

The Detroit Stamping Co. announces that it has added three "trigger-release" portable plier-type toggle clamps to the DE-STA-CO line of toggle clamps.



The manufacturer claims that this trigger action enables the operator to hold the workpiece with one hand, and clamp and release with the other. A touch of the trigger throws the jaws of these clamps open, ready for the next clamping action. These three new clamps are known as Models 482, 484 and 486.

A bulletin illustrating these clamps, important dimensions and typical applications of the same may be secured by writing Detroit Stamping Co., 340 Midland Ave., Detroit 3, Mich.

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Soldering Tools

ZEVA electric soldering tools are now being sold direct to industrial users, with 16 different styles, covering a range of 30 to 800 w.

The outstanding advantage claimed for these tools is the permanent, built-in heating element, hermetically sealed in cast aluminum, which is guaranteed to last as long as the tool itself.

Detailed information on the ZEVA line is available from Paul C. Roche Co., Inc., 11 Park Place, New York 7, N. Y.

ARCOS FOR FINEST QUALITY WELDS

Mountains crumble as **welded** jaws bite in

Modern power shovels gulp truckloads of rock and dirt at one bite. It's a good example of how *welded* high tensile steels make possible bigger payloads—provide extra strength and toughness to reduce maintenance.

An important factor in this achievement is the quality of weld metal. That's why so many fabricators today specify Arcos Low Hydrogen Electrodes when welding low alloy high tensile steels. *On any job* demanding shock and abrasion resistance . . . maximum strength and ductility, the excellent properties of Arcos weld metal assures the results you want in service. Arcos offers quality weld metal and technical assistance that is second to none. Arcos Corporation, 1500 South 50th Street, Philadelphia 43, Pa.

WELD WITH ARCOS LOW HYDROGEN ELECTRODES

DOCKSON ... Built for Better Service!

REGULATORS

STURDY CONSTRUCTION—Forged brass bodies, shatterproof gauges, dependable safety valves.

LOW COST—Replaceable, self-aligning seats; minimum of moving parts.

YOUR DOCKSON DISTRIBUTOR—a selected specialist stocks a complete line of Dockson Products to give you fast service and personal attention. We back our distributors 100%.

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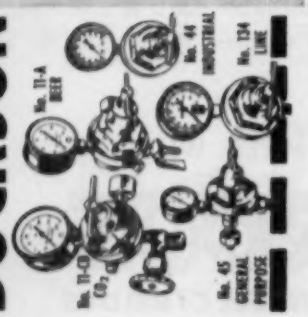
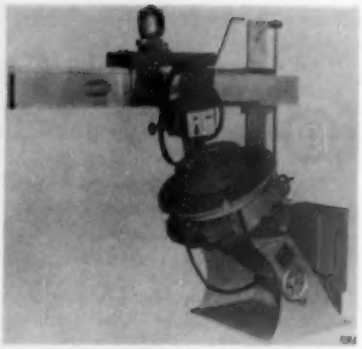


Combination Positioner

C. B. Herrick Mfg. Corp. announces that it has developed a new combination Mast-Ram-Positioner (Model CB MRP) recommended for metal fabricating shops or experimental laboratories using or contemplating automatic welding. Precision and ruggedness are emphasized throughout.

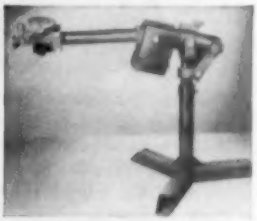
The work may be positioned or rotated under the welding head which is adjustable vertically and horizontally. Motorized, variable speed, lateral travel on the ram is available with the automatic head mounted on a travel carriage.

Another important feature is 360-deg rotation of the mast and ram. The automatic head can be swung around to work on another positioner, turning rolls, bench or floor job.

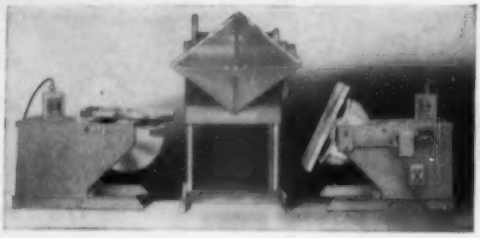


For full information, write to C. B. Herrick Mfg. Corp., 2000 Center St., Cleveland, Ohio.

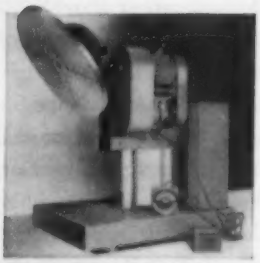
Steady, Positive, Precision Rotation for AUTOMATIC WELDING with *Aronson* Positioning Equipment.



UNIVERSAL Balanced POSITIONING
Model C 500 shown
25 lbs. to 2,000 lbs. capacity



HEAVY DUTY GEAR DRIVEN POSITIONING
Model HD 25 shown
500 lbs. to 24,000 lbs. capacity



HEAD and TAIL STOCK POSITIONING
Model HTS 5 shown
Capacities 5,000 lbs. to 160,000 lbs.

MODEL 21 (shown) SUPER GEAR DRIVEN POSITIONER with powered rotation tilt and elevation.

MODEL X-21 Powered rotation, ball bearing manual tilt and elevation.

MODEL 21-P Powered rotation and tilt, ball bearing manual elevation.

MODEL 21-E Powered rotation and elevation, ball bearing manual tilt.

MODEL X-21-PE Powered rotation, tilt and elevation, 5000 lbs. capacity @ 6" CG location.

Aronson TRACTRED Turning Rolls
Steady, positive, precision rotation for automatic welding. MODEL T1 (shown) capacity 6,000 lbs. per unit. MODEL T2 capacity 12,000 lbs. per unit. MODEL T3 capacity 18,000 lbs. per unit.

HEAVY-DUTY PRECISION BUILT RUBBER TIRED TURNING ROLLS
5,000 lbs. to 150 tons capacity

Aronson MACHINE COMPANY
ARCADE, NEW YORK

NEW LITERATURE

Safe Practices for Inert Arc Welding

The first and only publication covering all aspects of safety involved in the use of inert-gas metal-arc welding has just been published by the AMERICAN WELDING SOCIETY. By following the simple control measures recommended in this standard, safe working conditions can be assured.

The report, titled "Recommended Safe Practices for Inert-Gas Metal-Arc Welding," represents the findings of a special subcommittee of the AWS Committee on Safety Recommendations, and is based on laboratory studies, the experience of industry to date, and an extensive review of the literature and industrial records.

All known potential hazards peculiar to the inert-gas metal-arc process are covered in the report. The findings of the committee, comprising both medical and technical men, showed that no significant hazards exist from either ozone or nitrogen oxide, and contrary to some early reports, that there is no dangerous amount of radioactivity given off by thoriated-tungsten electrodes.

However, the report focuses attention on the hazard of trichloroethylene when used in the vicinity of inert arc welding. Decomposition of trichloroethylene vapor by radiation from the welding arc produces noxious fumes including phosgene. Therefore, this chemical, often used in degreasing operations, should be so located that even minute quantities of vapor will not come in contact with the welding arc.

The publication also outlines adequate control measures for protecting workers from ultraviolet radiation and metal fumes produced in inert-gas metal-arc welding.

This standard is available in pamphlet form at a price of 50 cents. It can be obtained by writing to the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Iron Powder Electrodes Covered in Revised AWS Specification

Standard properties and performance requirements of the relatively new iron-powder electrodes are given for the first time in the revised edition of the Specifications for Mild Steel Arc-Welding Electrodes.

As described in the specification (A233-55T), these electrodes, designated E6024 and E6027, have coverings with a high percentage of iron powder in combination with fluxing ingredients. During welding, the iron powder fuses and deposits as weld metal along with the core wire. This increases deposit rate and makes them the fastest depositing of any manual-type electrode produced.

In addition to the iron-powder type electrodes, the specification covers the other standard lightly coated and covered metal arc-welding electrodes, such as the well-known E6010 and E6011 classifications, for welding of carbon and low-alloy steels of weldable quality. Details are given on test methods, test requirements, standard sizes and lengths, packaging, marking and color markings for identification. Handy tables giving classifications of all mild steel electrodes and a summary of tests and test requirements are also included.

The appendix contains complete details on the iron-powder electrodes, including current and voltage ranges for various diameters, description of welds produced and a list of strength and ductility properties to be expected. The appendix also provides corresponding information on the other classes of electrodes.

Copies of this specification in pamphlet form are available from the AMERICAN WELDING SOCIETY and the American Society for Testing Materials at 40 cents each.

Portaflux Booklet

A new 8-page booklet titled "Norelco Portaflux—New Portable Magnetic Particle Test Unit"—which describes a method for checking ferrous metal objects for surface discontinuities, is available gratis from the Mount Vernon Division, North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.

The new literature explains how the method is used in automotive, aircraft, rail and many other industries which depend on high-quality metal products.

Illustrated with many photos, drawings and diagrams, the new booklet gives a complete description of the basic principle on which magnetic particle testing is based. It also tells about various inspection procedures and describes in detail how the Portaflux is operated.

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Profits from Welding

"More Profits from Welding" (TIS 2328), a new folder in color for job and contract welders, is now available free from Eutectic District Engineers and Eutectic Welding Alloys Corp., Flushing 58, N. Y.

An illustrated spread shows the job welder which "low-temperature welding alloys" to prescribe and use for cast iron, aluminum, steels, copper and soldering and metalworking jobs. This part of the folder is also available in enlarged shop or window poster form, headed "Welding Wanted," which the job welder can use to promote more profitable business.

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Copper-Alloy Electrodes

Ampco Metal, Inc., has released a new Bulletin W-26 describing Mang-Trode electrodes in detail.

Mang-Trode is a new electrode for use in the metal-arc welding of manganese bronze and the yellow brasses without preheat.

A copy of this bulletin can be secured from Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

Coating Moisture Investigations

The Welding Research Council has issued Bulletin 21, *Coating Moisture Investigations of Austenitic Electrodes of the Modified 18-8 Type*, by K. P. Johannes, D. C. Smith and W. G. Rinehart. This report gives rates of moisture absorption and desorption of austenitic welding electrode coatings of various temperatures and relative humidities. Copies may be purchased at $1.00 each through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

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Iron Powder Electrodes

"Iron Powder Electrodes and Their Application" is a reprint of a paper given before the 1954 AMERICAN WELDING SOCIETY National Spring Meeting by Jerry Hinkel, application engineer for the Lincoln Electric Co. The paper covers the theory of the new electrodes and explains why they have a basic advantage in higher deposition rates. Procedure information for the electrodes, their application, physical properties and operating characteristics are detailed. Typical production applications are illustrated with records of savings up to 50%. Reprints are available free from the Lincoln Electric Co., Cleveland 17, Ohio.

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Tooling for Welding

This new, enlarged 40-page edition illustrates and describes standard and special tooling, fixtures and machinery for high-quality, high-speed and low-cost welding. Includes excellent examples of special-purpose automatic-welding machinery using submerged arc and inert arc processes. "Tooling for Welding" is available from the 11 sales offices of the Cecil C. Peck Co. or their home office 14901 Woodworth Rd., Cleveland 10, Ohio.

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Alloy Steels Handbook

Available now for general distribution, a new 200-page hand-book entitled *Alloy Steels Pay Off* is offered by the Climax Molybdenum Co. to engineers, purchasing and management personnel who are interested in the practical utility of alloy steels in modern equipment design. Write directly to the Climax Molybdenum Co., 500 Fifth Ave., New York 36, N. Y.

New Welding Process

The performance and applications of a new consumable electrode inert-gas-welding process—West-ing-arc—are given in a new booklet available from the Westinghouse Electric Corp. This 7-page booklet answers the questions: What is West-ing-arc? What can it do? Where can it be used? What are the operating costs? What are the components?

For a copy of this booklet, B-6525, write Westinghouse Electric Corp., P. O. Box 2099, Pittsburgh 30, Pa.

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Airco Catalog

Air Reduction is offering a new 36-page catalog covering their complete line of arc-welding and oxy-acetylene-welding supplies and accessories.

Included in this booklet are welding rods, fluxes, brazing alloys, goggles, helmets, shields, electrode holders, protective clothing, cable, clamps, hose, lighters, cylinder trucks and carrying cases.

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REVIEWS OF NEW BOOKS

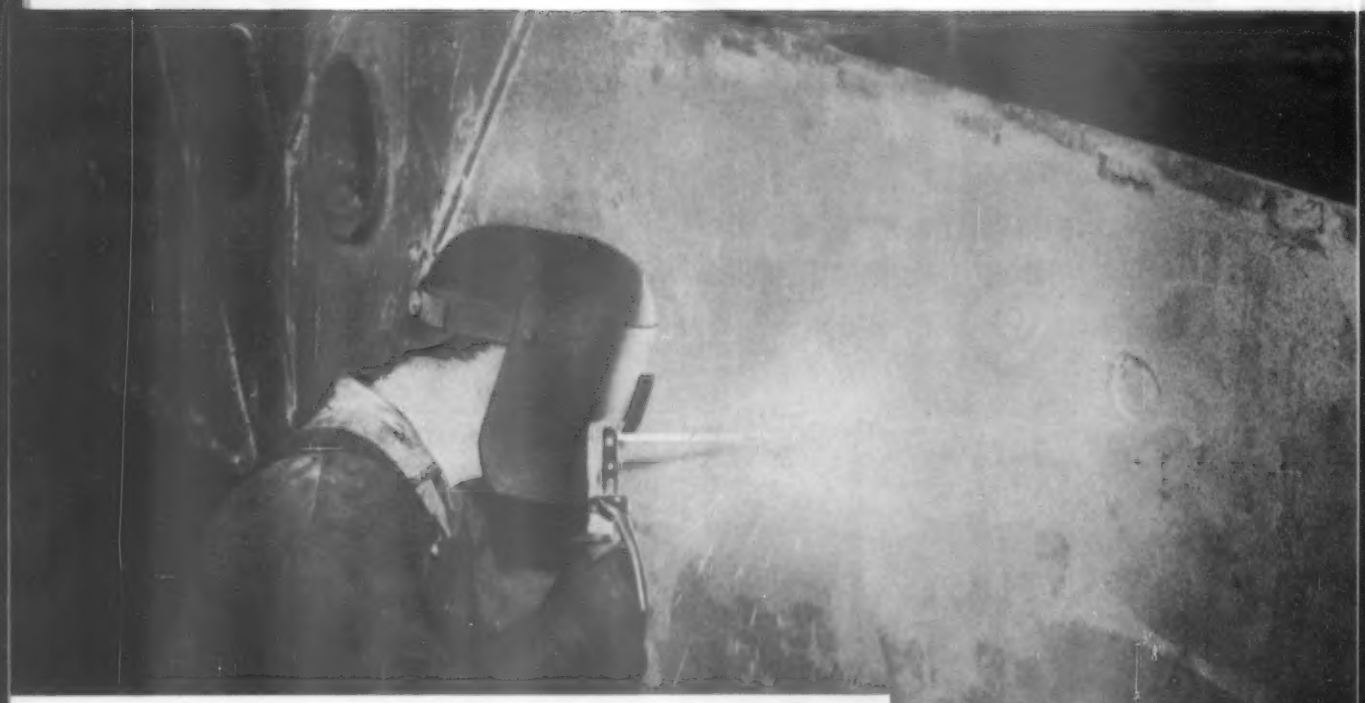
Principles of Machine Design

Principles of Machine Design, by Samuel J. Berard, Brown University, Everett O. Waters, Yale University, and Charles W. Phelps, Yale University. Price, $7.50. 534 pages, 53 tables, 321 illustrations. Published by the Ronald Press Co., 15 E. 26th St., New York 10, N. Y.

In scope and content, this book has been planned for the one-year engineering course which follows the courses in kinematics and strength of materials. Throughout, its aim is to develop rational and consistent methods of design, as applied to the more common elements of machine construction. Careful thought has been given to the relative importance of theory and conventional practice, and the exercise of sound judgment in the proportioning of parts.

The arrangement of subject matter is logical and one that the student should find easy to follow.

An important feature of this book is the emphasis placed on the present-day influence of welding in the whole field of design and construction.



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SUPPLEMENT TO THE WELDING JOURNAL, APRIL, 1955

PLASTIC FATIGUE PROPERTIES OF HIGH-STRENGTH PRESSURE-VESSEL STEELS

Plastic fatigue resistance of carbon and high-strength steels is influenced by steel composition, heat treatment, surface preparation, stress raisers, welding and cold work

BY J. H. GROSS AND R. D. STOUT

FOREWORD. The investigation reported in this paper was sponsored and guided by the Fabrication Division of the Pressure Vessel Research Committee, of which P. R. Cassidy and B. E. Rossi are former Chairman and Executive Secretary, and F. L. Plummer and J. H. Drucker present Chairman and Executive Secretary, respectively. The Project Steering Committee was composed of I. E. Boberg, L. C. Bibber, W. P. Gerhart and A. R. Lytle.

Introduction

The present paper is one of a series[1-3] covering a study of the resistance of steels applicable to pressure vessels to repeated loading in the plastic range. It was shown that plastic fatigue resistance is influenced by many factors, including steel composition, heat treatment, surface preparation, welding and cold work.

The general purpose of the investigation is to provide information on the fatigue resistance that may be expected from pressure vessel steels when cycled under loads high enough to cause plastic flow, such as might occur at stress-raisers present in a pressure vessel. Of particular interest in this connection are the high-strength steels which are under consideration for use in pressure vessels. In order to gain the full benefit of these high-yield-ratio steels, it is necessary to allow a design stress which is, say, half of the yield strength, and thus as much as 45% of the tensile strength, this in contrast to 25% of tensile strength customary with the carbon steels. At a design stress of this level, assurance is needed that no failures are likely to be induced by fatigue. The performance of six representative high-strength steels in plastic fatigue tests is reported here.

J. H. Gross is Instructor and R. D. Stout is Professor of Metallurgy at Lehigh University, Bethlehem, Pa.

Presented at the Thirty-Fifth National Fall Meeting, AWS, held in Chicago, November 1-5.

The Experimental Program

The Materials Division of PVRC selected six high-strength steels that appeared to be suitable for pressure vessel applications to be submitted to extensive mechanical tests, including plastic fatigue tests. The compositions, as-received heat treatments, and tensile properties of these steels are given in Table 1. Included also were heats of A-201, A-225 and Fortiweld Steels. Each of the steels was tested in plastic fatigue in the following conditions: (1) as-received, (2) as-received and notched (see Fig. 1) and (3) as-welded.

A second field of interest in this work has been to delineate the factors which control the resistance of steel to plastic fatigue failure. A number of tests was conducted to contribute further information on this subject, including the following variables:

1. Elevated temperature of testing—650° F.
2. Reduced cycling rate—1.5 cpm vs. 200.
3. Variable straining range.
4. Extension of the straining range to very high levels.

Details of these tests and the results obtained from them are presented in the next section.

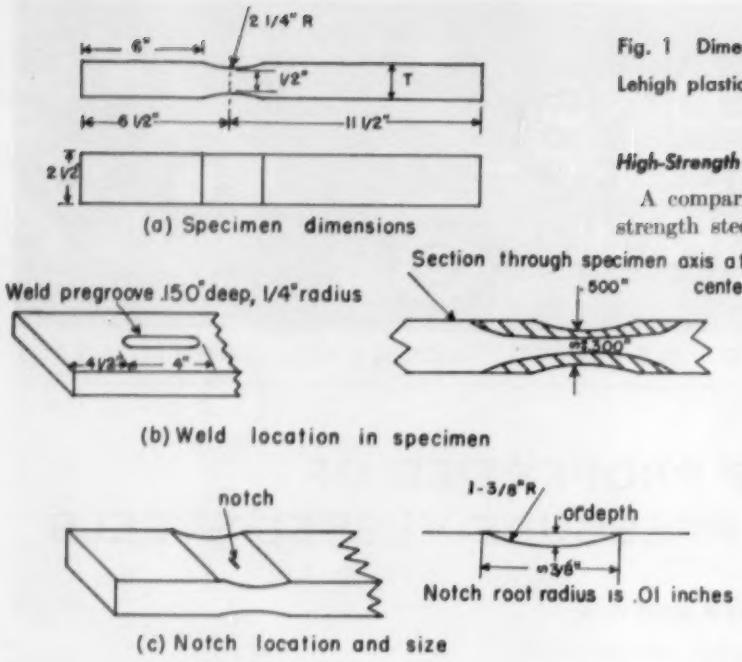

Fig. 1 Dimensions and preparation of the Lehigh plastic fatigue specimen

The Experimental Results

Testing Method

The fatigue specimens such as shown in Fig. 1 were loaded as cantilever beams to a series of constant deflections in the cam type machine. The straining range imposed on the outer fibers of the test section was measured on every specimen by means of an optical strain gage. Failure was indicated by inability of the specimen to transmit load to the fixed end. In addition, the cycles necessary to form a $^3/_{16}$-in. long crack were recorded to allow comparison with test results from the project at the University of Illinois. All tests were run in triplicate.

High-Strength Steels

A comparison series of tests was run on the high-strength steels listed in Table 1. Results for the as-received series are shown in Fig. 2. The sensitivity of these steels to a notch was determined by milling a small crescent-shaped notch 0.01 in. deep transverse to the specimen axis with a standard V-notch Charpy cutter without lateral movement of the cutter. In Fig. 3 the performance of the notched specimens is summarized.

The effect of welding on these steels was observed by locating longitudinal beads at the center of the pregrooved test section on both faces of the specimen. The weld reinforcement was machined flush before testing. Welding was performed with qualified electrodes and plate temperatures as follows:

Steel	*Plate temperature*	*Electrode, $^3/_{16}$ in.*	*Current, amp, and travel, ipm*
48s5	Room	E7016	200 at 6
A-302	Room	E7016	200 at 6
70A	Room	E10015	200 at 6
70B	Room	E9015	200 at 6
90B	Room	E12015	200 at 6
90A	200° F	E12015	200 at 6

The test data on the welded series are shown in Fig. 4.

Table 1—Analyses and As-Received Conditions of the High-Strength Steels

Steel	*Condition*	*C*	*Mn*	*P*	*S*	*Si*	*Ni*	*Cr*	*Mo*	*V*	*Ti*	*Cu*	*B*
		%											
A-201	Normalized	0.13	0.40	0.013	0.029	0.20	...	...	...	...	...	...	...
A-225	Normalized	0.20	1.28	0.023	0.035	0.15	...	...	...	...	...	...	...
48s5 HT	Normalized	0.15	1.12	0.034	0.031	0.18	0.06	0.05	0.017	0.085	0.007	0.11	...
Fortiweld	Normalized	0.13	0.49	0.023	0.042	0.236	...	...	0.48	...	...	...	...
A-302	Normalized	0.21	1.31	0.022	0.027	0.25	...	...	0.41	...	...	...	...
70A	Normalized and tempered	0.13	0.48	...	...	0.21	2.17	...	0.39	0.11	...	0.73	...
70B	As-rolled and tempered	0.21	0.75	0.017	0.033	...	2.04	...	0.22	...	...	0.95	...
90A	Quenched and tempered	0.31	1.45	...	...	0.25	...	...	0.12	...	...	...	...
90B	Quenched and tempered	0.16	0.93	0.014	0.023	0.26	0.87	0.50	0.45	0.06	...	...	0.0031

Tensile Properties of the High-Strength Steels

Steel	*Yield strength, 0.2%, psi*	*Tensile strength, psi*	*Elongation, %*	*Reduction of area, %*
A-201	38,500	60,500	35.5	68.2
A-225	52,500	76,100	29.2	65.0
48s5	48,400	70,600	31.7	70.0
Fortiweld	64,500	82,200	20.5	65.1
A-302	51,800	87,300	23.8	59.3
70A	79,200	95,200	25.5	71.0
70B	84,800	101,800	19.5	56.2
90A	113,000	129,500	17.5	61.5
90B	123,400	130,000	15.5	50.2

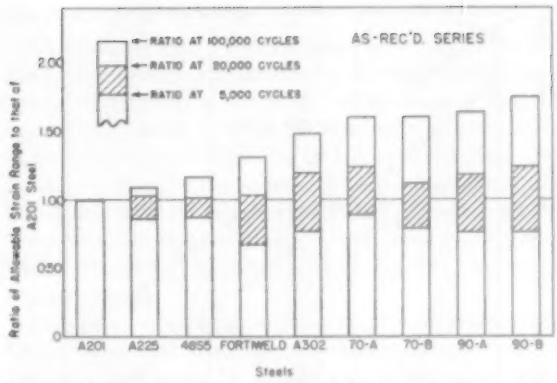

Fig. 2 Comparison of as-received, high-strength steels to A-201 steel as to allowable strain range for fatigue life of 5000, 20,000 or 100,000 cycles

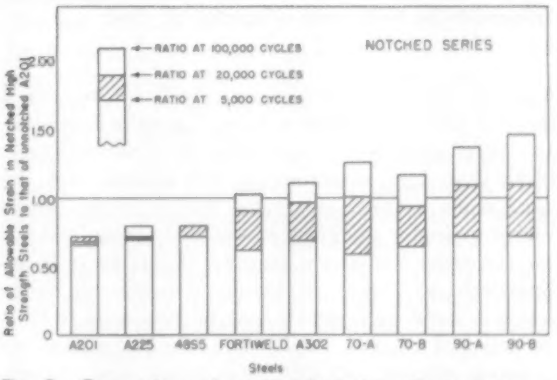

Fig. 3 Comparison of notched high-strength steels to unnotched A-201 steel as to allowable strain range for fatigue life of 5000, 20,000 or 100,000 cycles

Elevated Temperature Tests

A few series of tests were conducted on A-201 and A-302 steels at 650° F by enclosing the specimen with its gripping vise in a furnace. A comparison of the performance of these steels at 650° F with that at room temperature is presented in Fig. 5. The significant feature of the comparison is that both steels showed a noticeable improvement in fatigue resistance at the elevated temperature.

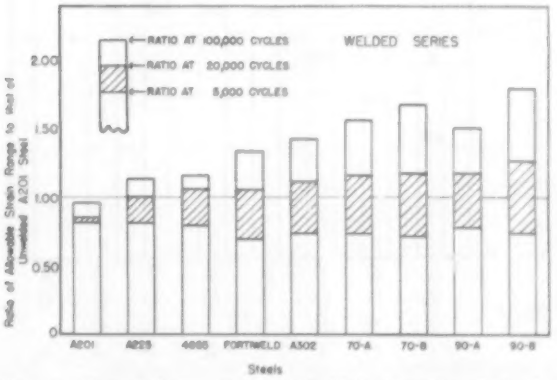

Fig. 4 Comparison of welded high-strength steels to unwelded A-201 steel as to allowable strain range for fatigue life of 5000, 20,000 or 100,000 cycles

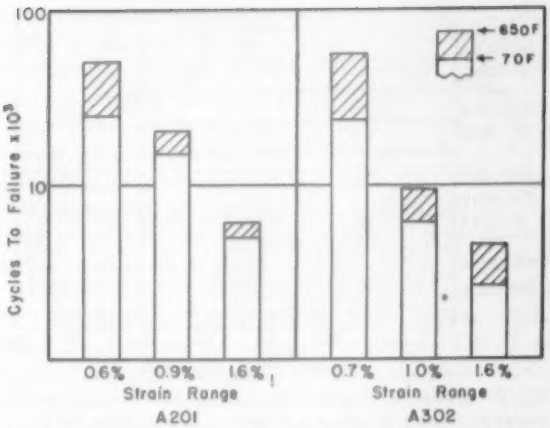

Fig. 5 Improvement of fatigue life of A-201 and A-302 steels when tested at 650° F. instead of room temperature

Study of Cycling Rate

There is some evidence that very slow rates of cycling result in shorter fatigue life than rapid cycling. It was considered desirable to check this point in the plastic range of interest in the present investigation. In order to study slower cycling rates than the standard 200 cpm used for all other tests, a gear box was rigged to the machine to provide a rate of 1.5 cpm. The data for A-201 and A-302 steels tested at the two speeds are plotted in Fig. 6.

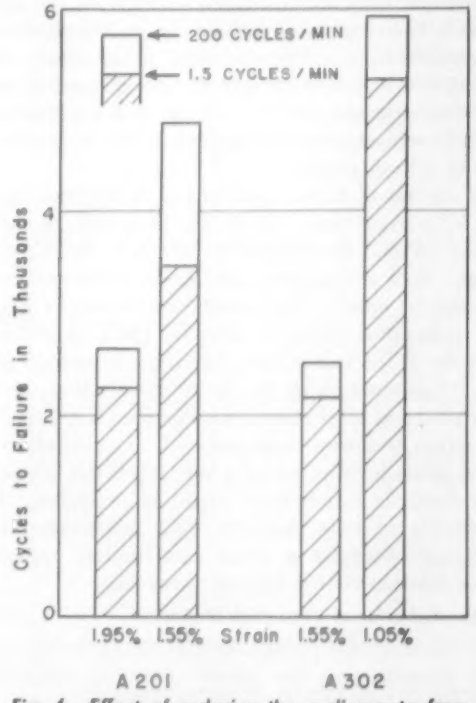

Fig. 6 Effect of reducing the cycling rate from 200 to 1.5 cpm on the fatigue life of A-201 and A-302 steels

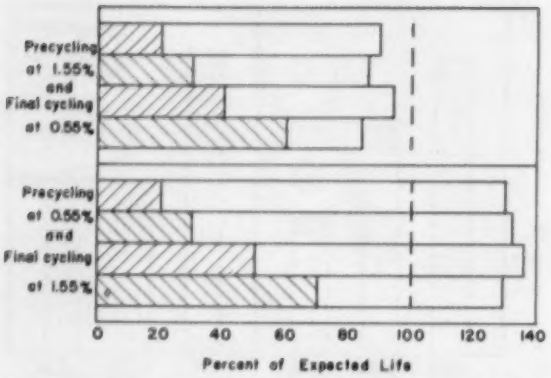

Fig. 7 Influence of precycling at one strain range on the cycles to failure at either a higher or lower strain range

As an average, the 130-to-1 reduction in cycling speed reduced the fatigue life about 10–15%. It is possible that service loading involving cycles lasting hours or days would reduce fatigue life 25% or more. This question requires further consideration for a definitive answer.

Variable Straining Range

In the laboratory testing of fatigue resistance it is almost universal practice to impose a constant maximum load or deflection on a given specimen; while in service loading, the magnitude of the load may vary irregularly from one cycle to the next. A few tests were undertaken to learn if cycling at two different strain levels would result in a fatigue life which was predictable from the behavior at each of the strain levels. This was accomplished by cycling specimens at one level for, say, 20, 40 or 60% of the expected life at that level and then cycling to failure at a second level. If the action is cumulative, the life at the second level could be expected to be respectively 80, 60 or 40% of that of a fresh specimen.

In one set of tests, specimens of A-302 were cycled at 1.55% strain range for 20, 30, 40 or 60% of the expected life and then cycled to failure at 0.55% strain range. In a second series, the strain levels were interchanged in order. The results are shown in Fig. 7. The ordinate is scaled in terms of 100% expected fatigue life if the two stages of testing are strictly additive. Examination of the figure reveals that when a high straining level precedes a low one, the life at the low strain is shorter than expected. Conversely when a low strain level precedes a high level, the life at the high strain is longer than would be predicted. It is interesting to note that the total percentage life is quite consistent for a given combination, regardless of the fraction contributed by precycling.

Fatigue Behavior at Very High Strains

It was suggested previously that the cycles to failure vary linearly with the plastic straining range (i.e., total strain less the elastic strain) when plotted on a log-log graph. In order to find whether this relation is maintained at higher straining ranges, the testing

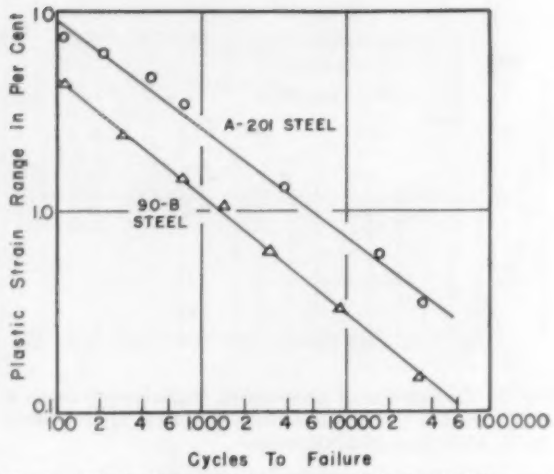

Fig. 8 Relation between the range of plastic straining and fatigue life for A-201 and a high-strength steel

level was extended to 9% strain. In Fig. 8, tests on a heat of A-201 steel show a linear logarithmic relation that is followed closely from 0.4 to 9% straining range. Note that only *plastic* strain was plotted, not the *total* strain. Thus, the more ductile A-201 shows higher cycles for any given *plastic* strain range, but not for the lower *total* strain ranges. If this curve is extrapolated to 1 cycle at failure, the straining range value is about 80%, which may be compared to 68% reduction of area in a tensile test. The 90B steel shows a similar relation, but with lower plastic strain values. Extrapolation of the curve indicates 65% strain at one cycle compared to 50% reduction in the tensile test.

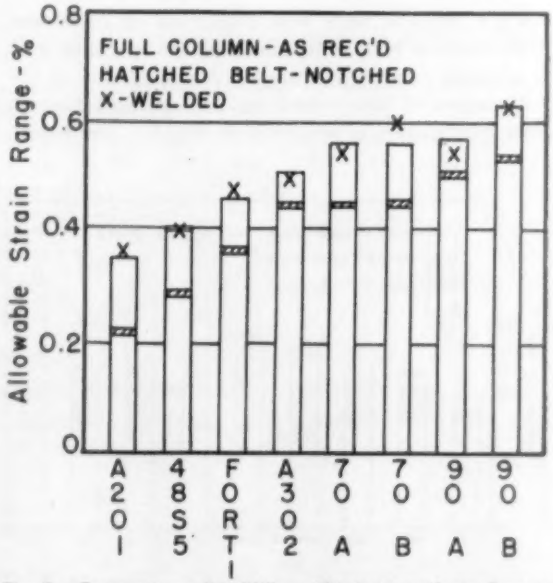

Fig. 9 Comparison of A-201 and high-strength steels as to allowable strain for 100,000 cycles fatigue life in the as-received, as-notched and as-welded condition

Discussion of results

The data in Fig. 2 indicate that generally the high-strength steels show a superiority increasing with their tensile strengths at a fatigue life in the range of 100,000 cycles. However, at very high strain levels resulting in a fatigue life of only a few thousand cycles they lose their advantage. The ability of all the steels to withstand over 1% strain range for so many cycles is quite reassuring, since this range is well above the level which should be encountered in a properly designed pressure vessel.

It is possible to analyze these results on several different bases. If one assumes that a fatigue life of 100,000 cycles would be an adequate performance for a pressure vessel, it is interesting to compare the strain levels that these steels will endure for 100,000 cycles. In Fig. 9, the allowable strain range is plotted for each steel, showing more clearly the rise with tensile strength. The full column represents the as-received behavior. In the same figure, the effects of welding (indicated by the "X" points) and of notching (indicated by the hatched belt within the column) are also indicated. The welded performance was essentially the same as unwelded. Notching lowers the allowable strain, as shown in Fig. 9, but the reduction is less than might be expected from the stress-raising factor of the notch.

If these steels are to be used at a design stress which is one-half or some other fraction of the yield strength, they must show a satisfactory fatigue life at stress levels which are considerably higher since stress raisers in the vessel may produce such stresses. On the assumption of a stress-raising factor of two and a fatigue life of 100,000 cycles, it is interesting to calculate the allowable design membrane stress for each of the steels. These are compared in Fig. 10, in which the specified minimum yield strengths are also shown. It is apparent that the allowable membrane stress according to the fatigue data does not rise proportionately to the yield stress. While these values are comparative only, they emphasize the need for proper design and careful fabrication of pressure vessels intended for high operating stresses, in order to avoid unfavorable stress raisers. An important question in connection with the plastic fatigue performance of high-strength steels is whether fatigue resistance correlates better with tensile strength or with yield strength. In Fig. 11 the allowable straining range corresponding to a life of 100,000 cycles is compared to yield strength and to tensile strength for the steels investigated. The allowable strain rises more slowly with yield than with tensile strength and shows more tendency to scatter. This point will receive more extensive investigation in the continuing program.

The A-302 steel provided an interesting opportunity to compare the influence of yield and tensile strength. When the normalized material is stress relieved at 1100° F the yield strength rises from 52,000 to 62,500 psi, while the ultimate drops from 87,500 to 81,700 psi. The fatigue performance showed about 15% decrease after stress relief. Thus, the controlling position of tensile strength is further supported.

Some comments are in order concerning the general interpretation of these results. Like all fatigue tests conducted on an arbitrary specimen, these experimental results are valuable for qualitative comparison rather than for quantitative evaluation or direct application to service conditions. It is felt, however, that these tests do provide a valid comparison between steels, as well as between specimens into which have been introduced other variations by heat treatment, welding or surface preparation. What cannot be done is to apply the allowable strain ranges measured in the laboratory directly to engineering structures. These comments are supported by the results of a corollary investigation on a different specimen design at the University of Illinois,[4,5] which has corroborated the findings of the investigation reported here as to the effect of such variables as surface preparation, welding and steel strength level. At the same time, the two specimens show a disparity in allowable strain ranges for a given fatigue life for several readily understood reasons.

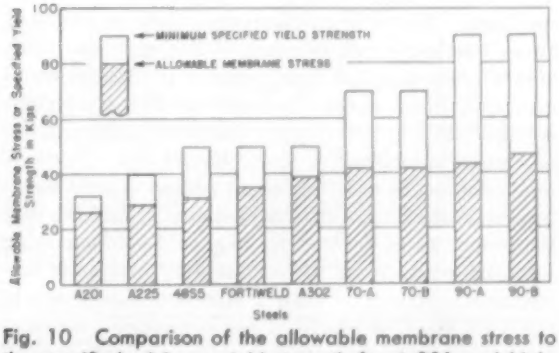

Fig. 10 Comparison of the allowable membrane stress to the specified minimum yield strength for A-201 and high-strength steels, assuming a desired fatigue life of 100,000 cycles and a stress-raiser factor of 2

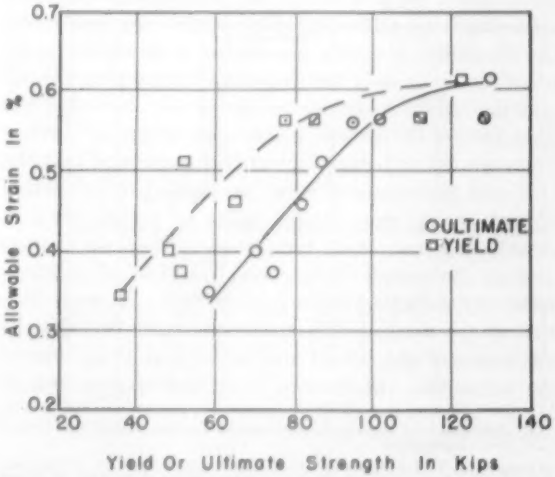

Fig. 11 Relation of allowable strain range for 100,000 cycles fatigue life to the yield and tensile strengths

One of these is the difference in the criterion of failure. The upshot of these points is that the usefulness of these investigations should not be overextended to deriving design or service data on plastic fatigue resistance.

Summary

The results of this investigation can be summarized as follows:

1. For a fatigue life of 100,000 cycles, the allowable straining range increased as the tensile strength of the steel was raised from 60,000 to 120,000 psi.

2. Welding had a negligible effect on the fatigue resistance of the high-strength steels investigated when the reinforcement was removed. Notching lowered fatigue life in all steels but not as severely as would be expected from the stress-raising factor.

3. From the viewpoint of fatigue, carbon steel can be design loaded to a higher fraction of its yield strength than can the higher strength steels (when stress raisers with a factor of 2 and a life of 100,000 cycles are assumed). Tensile strength rather than yield strength seems to control fatigue resistance in these steels.

4. When the testing temperature was raised from room temperature to 650° F, both A-201 and A-302 steels showed higher plastic fatigue resistance at all levels of straining range.

5. A change in cycling rate from 200 to 1.5 cpm lowered the fatigue life of both A-201 and A-302 steels about 10–15%. Thus, in service, some allowance might be necessary for conditions involving very low cycling rates.

6. The results reported here are for comparative purposes rather than for quantitative evaluation of service fatigue life. They are believed to be valid for studying the effects of variables important to plastic fatigue.

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DISCUSSION OF PAPER:

EFFECT OF ELECTRODE TYPE IN THE NOTCH SLOW-BEND TEST

DISCUSSION BY C. E. HARTBOWER AND AUTHORS' REPLY

From the introduction of the paper it is understood that the objective was to investigate the possibility of a correlation between the Kinzel test and the explosion-bulge test and, in particular, to determine whether the Kinzel test would show the controlling effect of weld metal notch toughness and flow strength as shown by explosion-bulge tests of pearlitic steels. In considering the possibility of such a correlation, it should be recognized that not only are equivalent transition criteria and definitions essential to correlation but also the mechanics of the test specimens must be similar. When investigators at Lehigh University[1] contended that the choice of test specimen is far less critical to correlation of test results than is the choice of criteria used in establishing transition temperature, they were overlooking the complex interplay of mechanical and material variables that affect performance. In consideration of the marked differences that exist between the mechanics of the Kinzel and bulge tests, it appears to the writer that the chances of correlation were remote because the standard Kinzel test cannot be expected to respond to variations in weld metal properties in the same way as the bulge test with its balanced biaxial load field.

The mechanics of the explosion-bulge test have been covered previously in some detail.[2] A number of comments appear pertinent concerning the mechanics of the Kinzel test. As in all bend tests (particularly with a transverse notch), the principal stress in the Kinzel test is in the direction of the longitudinal axis of the specimen. With a longitudinal weld, this component of stress necessarily causes equal straining in the weld, heat-affected zone and base metal in the Kinzel specimen, and, therefore, the overmatching effect of a higher-strength weld in producing a transweld strain deconcentration is inoperative in the Kinzel test. Furthermore, due to the relatively small volume of weld metal present in the 3-in. wide test specimen, it appears that the properties of the base metal should be dominating (at least when lateral deformation is used as a performance criterion). With a standard Kinzel notch, the weld metal is nearly, if not completely, removed from the path of fracture and, moreover, only a small portion of heat-affected zone remains in the test section.

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The paper by W. J. Murphy and R. D. Stout, entitled "Effect of Electrode Type in the Notch Slow-Bend Test," was published in The Welding Journal, **33** (7), 305-s (1954).

The opinions expressed in this paper are those of the discusser and do not necessarily express the views of the Ordnance Corps, USA.

When the notch-depth was varied by pregrooving, the results might have been more easily understood if an attempt had been made to determine where fracture initiated. For example, if fracture were to initiate in the heat-affected zone, then little difference in the ductility transition temperature (nil prefracture-deformation) would be expected with or without a small volume of stainless weld metal under the notch. When the Kinzel test was modified by pregrooving, a slightly increased volume of E-310 weld metal at mid-section appears to have lowered the transition temperature approximately 20° F (Fig. 5 of the paper). It is difficult to understand why a small volume of weld metal (however tough it might be) would overshadow a relatively notch-sensitive heat-affected zone. The use of multiple bead-on-plate specimens presents an even more complicated picture (Fig. 7 of the paper): (1) Deposition of three beads side-by-side (center bead last) has a marked tendency to produce underbead cracking[3] due to the superposition of welding stresses, (2) comparisons between single- and multiple-bead test results must take into consideration the possibility that transformation products in the heat-affected zone are altered with a multiple-bead technique; (using the ductility transition criteria, there was only a difference of 20° F between the single- and multiple-bead-on plate tests; with so great a scatter, it is questionable whether 20° F is a significant difference) and (3) in the case of the double-vee butt welds using E-60 and E-120 type of electrodes, the higher transition temperature in the case of the E-120 type electrode may have been caused by vanadium-carbide precipitation.[4]

With regard to the authors' definition of transition temperature, a few comments appear in order concerning the meaning and measurement of lateral contraction. Lateral contraction was described as a criterion of transition temperature by Kinzel in the 1947 Camp-

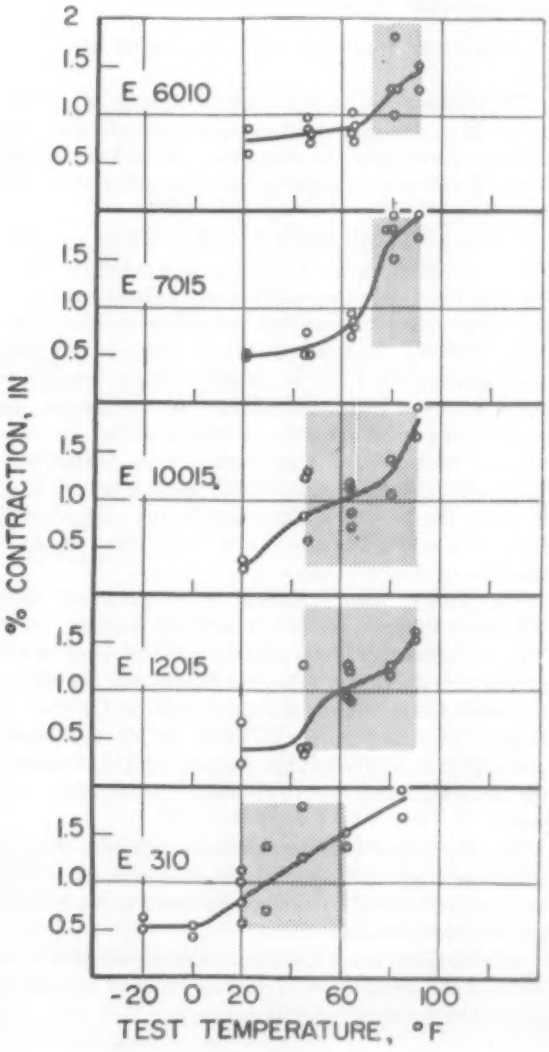

Figure 1

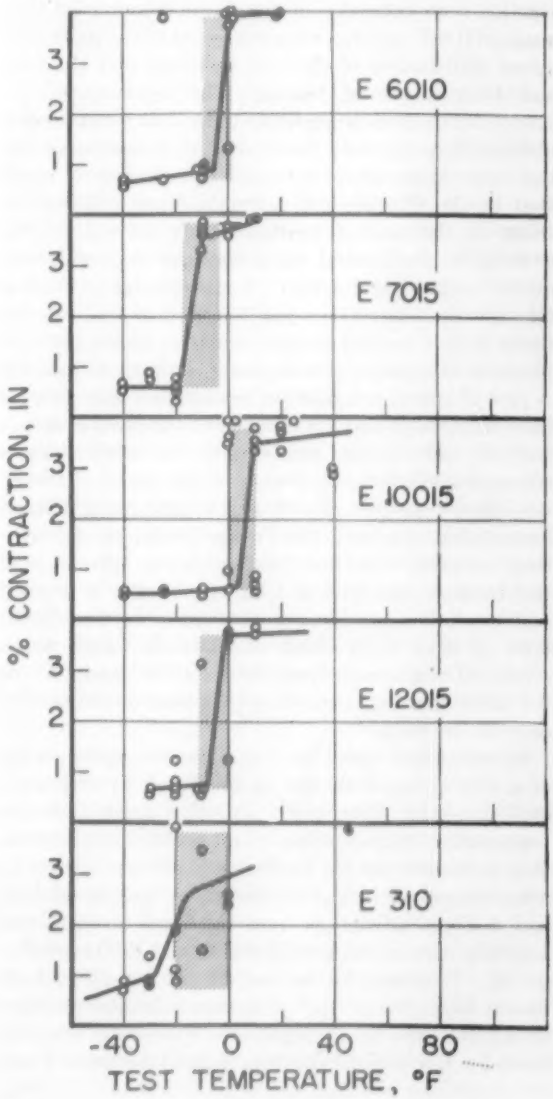

Figure 2

bell Memorial Lecture.[5] Kinzel's selection of performance criterion was based on the observation that whenever a crack fails to traverse an entire structure in service failures, fibrous areas appear at the edges near the end of the fracture; and that whenever this occurs, there is a small but perceptible reduction in cross section of the plate. In laboratory test specimens, contraction was measured adjacent to the notch using a micrometer caliper. With temperature as a variable for matching test to service, Dr. Kinzel defined transition temperature in a 3-in. wide notched bar as that temperature at which the specimen showed a 1% lateral contraction parallel to the notch. The value of 1% contraction was thought to correspond approximately to the deformation in service failures at the section near the end of cracks which stop propagating.

Since its introduction, lateral contraction has been used by a number of investigators as a performance criterion. It is generally accepted that lateral contraction is an indication of the plastic deformation that a material will undergo when subjected to the particular stress distribution of the test specimen and the rate and temperature of testing. The measurement of lateral contraction is generally treated as separate and distinct from the work done (energy) in fracturing the test bar. However, recently it has been demonstrated that in the Charpy test a simple linear relationship exists in the case of pearlitic steels between lateral contraction and lateral expansion and the energy required to produce fracture.[6, 7] Knowledge of such a relationship is more than just a matter of academic interest if it is desired to compare tests which differ in physical dimension, notch acuity, or rate of loading. A plot of lateral deformation versus work done to produce fracture provides a measure of the relative resistance to deformation and a basis for establishing a common performance criterion in the study of transition characteristics. Puzak and Pellini[8] recently demonstrated that a particular energy (or lateral deformation) criterion which is suitable for one type of steel (for example, the 15 ft-lb Charpy criterion in rimmed and semikilled steel) may not apply to a different type of steel (fully-killed and low-alloy high-tensile steel). Thus, comparisons between "K" and "L" on the basis of a single criterion (1% lateral contraction) may not be valid.

In connection with Figs. 1 and 2 of the paper, the use of a scatter band similar to that used in evaluating explosion-bulge data (with attention focused on the temperature corresponding to nil prefracture deformation) indicates that the E-100 and E-120 type electrodes when deposited in the plain-carbon base metal "K" had a slight advantage over the lower-strength and generally more notch-sensitive E-60 and E-70 type electrodes. However, in the case of the low-alloy, high-tensile base metal "L," differences in the ductility transitions were hardly significant (transition temperatures for the various deposits ranged between 0 and −20° F). It appears that the performance characteristics of the base metal were a major factor in controlling the performance of the Kinzel test specimen. It might have been enlightening if the authors had provided base metal transition curves. This would have shown conclusively the effect of the small volume of weld metal and heat-affected zone on lateral contraction measurements in the standard Kinzel specimen.

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AUTHORS' REPLY

The authors appreciate the comments of Mr. Hartbower.

The authors are in full agreement with Mr. Hartbower as to the basic differences between the test conditions obtaining in the explosion test and the Kinzel test. These were summarized on page 307-s of the paper.

The unwelded base plates showed transition temperatures of −50° F for the A-212 steel and below −100° F for the Mn-Ti high strength steel. These were considerably below the welded transition temperatures, and therefore, the weld metal and heat-affected zone must be responsible for the change. Since variation in the weld metal had little influence on the results, the heated zone must be assigned responsibility for controlling the transition temperature in the Kinzel test.

The effect of the austenitic weld metal appeared to be to delay the growth of the crack in the heat-affected zone by a supporting action of a tough crack-resistant material in close proximity.

The authors have examined the behavior of these test series at lower levels of lateral contraction ($^1/_3$ to $^1/_2$%) in order to allow comparison at the range of nil-prefracture ductility. The conclusions are essentially the same for this lower ductility range as for the 1% range. The shaded areas indicated by Mr. Hartbower are located at relatively high-ductility ranges, especially for the E-6010 and E-7015 electrode tests on the A-212 steel.

Mr. Hartbower cautions against comparison of steels of different type by means of the same criterion. This is a good point, and no such comparison was made in the paper under discussion.

It is obvious that a good deal of work remains to be done on the significance of various types of laboratory tests to actual service performance.

THE HEAT-AFFECTED ZONE IN ARC-WELDED TYPE 347 STAINLESS STEEL

Although the room-temperature impact strength of the heat-affected zone in the as-welded condition is not different than the base metal there is a considerable loss in ductility at elevated temperatures in the region heated to 2400° F during welding

BY E. F. NIPPES, H. WAWROUSEK AND W. L. FLEISCHMANN

ABSTRACT. This investigation was undertaken to establish the properties of Type 347 stainless steel in regions adjacent to arc welds mainly for a study of the effect of these properties upon the behavior of weldments at elevated temperatures. Specific microstructures associated with definite regions of the weld heat-affected zone were produced synthetically on the RPI time-temperature controller. Samples with uniform microstructure were obtained in sufficient size that the usable test specimens could be prepared. These samples were then used to study some of the mechanical and metallurgical change brought on by welding and as a consequence of postweld heat treatment. The room temperature impact strength exhibited a slight decrease in the samples heated to the highest peak temperature (2500° F). The rupture test at 1100° F of specimens heated at 2400° F showed a significant decrease of ductility. To study the carbide precipitation occurring in the weld heat-affected zone upon exposure within the sensitization range, a series of as-welded specimens were given a 1200° F treatment. Those samples which were originally heated to above 2400° F before the sensitization treatment exhibited severe attack by boiling 65% nitric acid. Photomicrographs are presented showing the metallurgical changes in the weld heat-affected zone.

Introduction

The austenitic steels of the 18 chromium–8 nickel series were developed for their corrosion resistance. However, it was noticed that the resistance to corroding media was affected by the thermal history of the steel. Addition of an element, be it columbium or titanium, was found to make the steel less sensitive to corrosion after heat treatments by stabilization of the carbides.

In the search for good heat-resistant materials, it developed that the columbium stabilized grade (18Cr–8Ni-Cb), known as AISI Type 347 stainless steel, had creep and rupture properties superior to the unstabilized grades. Hence, that steel has been specified in many high-temperature installations in the oil and power industry, where joining by welding is common practice.

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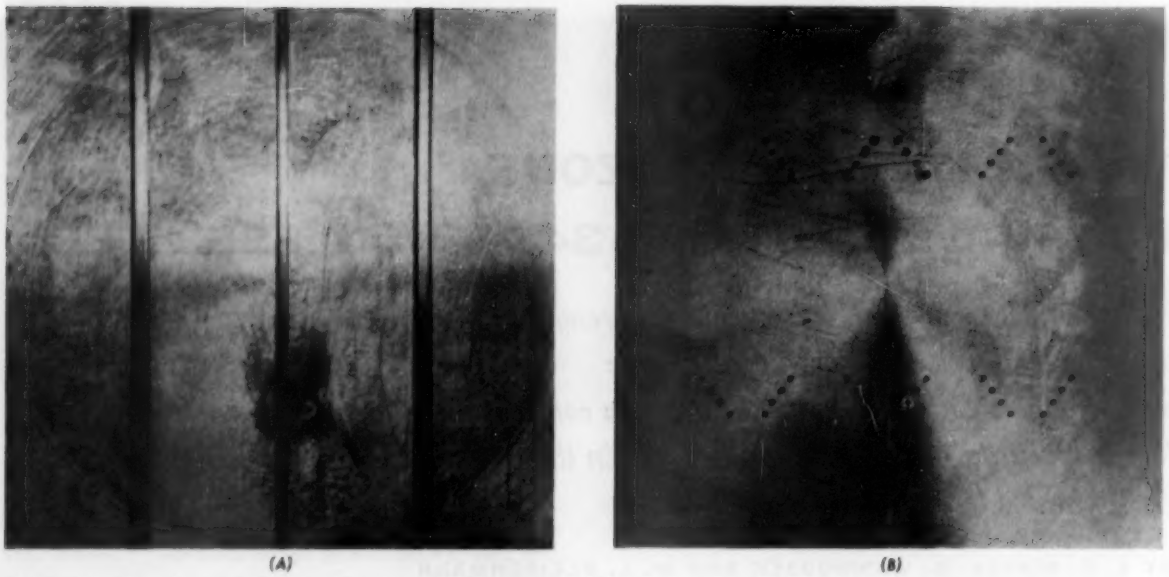
This work was done at RPI under Atomic Energy Contract AT (30-3)93 in conjunction with the Knolls Atomic Power Laboratory.

In the 300 series, Type 347 stainless steel is considered to be a grade that can be welded because corrosion resistance is maintained in the weld heat-affected zone without a postweld heat treatment. Yet, when heavy sections were to be welded, it was not an uncommon experience to observe cracking in the weld heat-affected zone right after welding or after some postweld heat treatments. Also, after some time at elevated temperature service, cracks appeared adjacent to some welds. The chemical industry experienced attack by corrosion in a narrow band in the weld heat-affected zone ("knife-line" attack).

The weld heat-affected zone consists of incremental regions, each one having a slightly different thermal history. Hence there is a continuous change in the metallurgical structure which usually is reflected by variations in properties. To facilitate a correlation of microstructures and properties with a thermal cycle, it is necessary to have for test purposes specimens which contain definite, uniform microstructures identical to those found in the various locations of the weld heat-affected zone. In this way the properties of the individual microstructures present in the heat-affected zone can be investigated.

The welding laboratory at the Rensselaer Polytechnic Institute developed a time-temperature controller designed to simulate within a reasonably sized specimen heating and cooling cycles as they occur in any part of the weld heat-affected zone. Thus microstructures as they exist in the weld heat-affected zone are synthetically produced.

Section I of this paper covers the determination of thermal cycles occurring at various locations in the weld heat-affected zone of $1^1/_2$-in. thick Type 347 stainless steel plate. Section II includes test results (microstructures, impact strength, rupture strength at 1100° F, and the effect of a sensitization treatment on resistance to nitric acid attack) obtained from speci-



(A) (B)

Fig. 1 Welding plate. (A) Top side with welding groove; (B) bottom side with holes for thermocouples

mens representing a number of typical thermal cycles which produced the characteristic heat-affected zone of $1^1/_2$-in. Type 347 stainless steel plate. Section III is a discussion of results.

Determination of Thermal Cycles Occurring Within the Heat-Affected Zone During Arc Welding

The production of test specimens representing specific microstructures within the weld heat-affected zone requires a knowledge of the different weld heating and cooling cycles occurring in the region from the fusion line to the unaffected base metal. The thermal cycles are dependent on three external variables, plate thickness, heat input and preheat. Because cracking in the weld heat-affected zone seems to occur most frequently in heavy sections, the geometry selected for the determination of the thermal cycles was a plate $1^1/_2$ in. thick. The thermal data obtained from welding such a heavy section are considered applicable to thicknesses as low as 1 in. and are valid, for metallurgical purposes, for any section thickness above $1^1/_2$ in. Hence the results obtained from the $1^1/_2$-in. plates cover adequately the thickness ranges employed in the structures of power equipment.

A $^5/_{32}$-in.-diam electrode is commonly used for these thicknesses. The recommended operating conditions for this size electrode are 22 to 25 v and 105 to 160 amp, which in this investigation were held at 23 v and 130 amp (reverse polarity). Three travel speeds were selected: 4, 6 and 9 ipm, representing energy inputs of 45,000, 30,000 and 20,000 joules per inch, respectively. Also from prior work at RPI with this testing procedure, the data can be extrapolated for the design of cams simulating the thermal cycle produced by $^3/_{16}$-in. electrodes.

Table 1—Arc-Weld Runs on $1^1/_2$-In.-Thick Type 347 Stainless-Steel Plate

Preheat, ° F	*Arc voltage, v*	*Arc current, amp*	*Travel speed, ipm*	*Energy input, joules/in.*
None	23	126	8.5	20,450
None	23.2	130	5.85	30,950
None	23	135	5.5	33,900
None	23.5	126	4.51	39,400
None	23.5	135	3.95	48,200
325	23.5	130	8.44	21,700
310	23	128	5.95	29,700
305	23.5	131	4.22	43,770

As the usual welding procedure for Type 347 stainless steel does not call for preheat and limits the interpass temperature to 300° F, the majority of arc-weld runs were made without preheat. Only one set of test runs was performed to determine thermal data for a preheat of 300° F (Table 1), so that the data for the highest permissible interpass temperature are available.

The preparation of the $1^1/_2$-in.-thick plate (12 in. square) consisted of machining a groove on one side ($^3/_8$ in. wide and $^1/_{16}$ in. deep) and drilling thermocouple holes 0.052-in. diam from the underside to within 0.050 in. of the upper surface. The thermocouple holes were spaced in a fanlike fashion between 0.2 to 1.25 in. from the groove center line, Fig. 1. Before each welding run, chromel-alumel thermocouples were percussion welded to the bottom of the thermocouple holes. The welding was done on a General Electric automatic arc welder, and the electrical data were recorded on recording-type meters. A 14-channel oscillograph was used for recording the output of the thermocouples. A typical oscillograph trace is shown in Fig. 2.

The oscillograph traces give the temperature data as a function of the time after the arc has passed the specific thermocouple location. Thus from a single

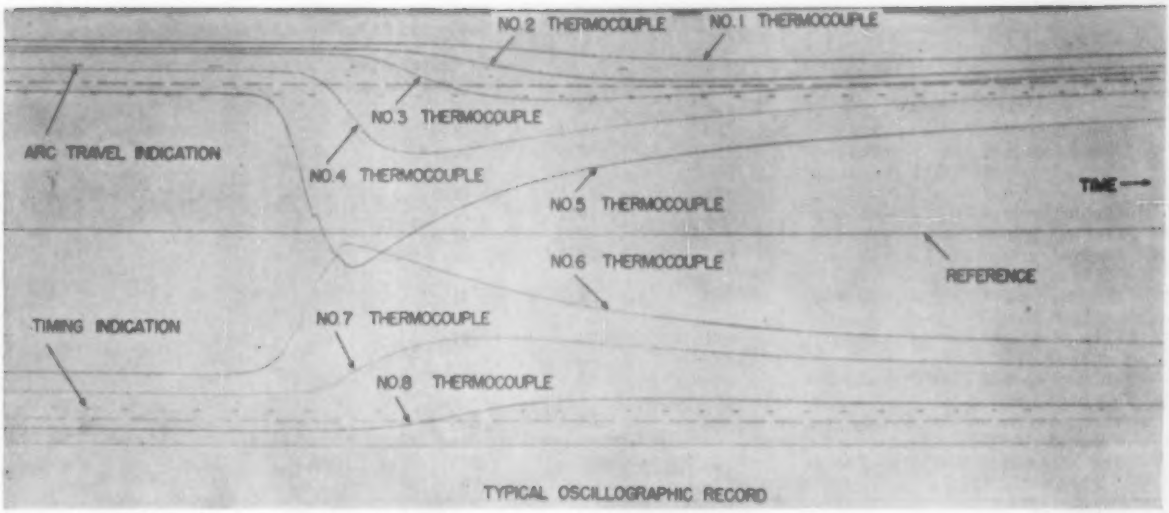


Fig. 2 Record from the 14-channel oscillograph

The timing indications are spaced at 5-sec intervals. Each arc travel indication represents 1 in. of arc travel.
Note: The direction of the displacement of some of the thermocouple traces is reversed to facilitate reading of the record.

arc-weld run of a given energy input and preheat, thermal cycles occurring at the eight thermocouple locations are obtained. In Fig. 3 are shown several such thermal cycles. The thermal data obtained from the oscillographs of weld runs of various energy inputs may also be expressed in terms of a generalized function, independent of energy input and preheat. This function, its associated values and its usefulness are presented in an appendix to this report.

Initial Study of Some Properties of the Weld Heat-Affected Zone in Arc-Welded Type 347 Stainless Steel

A limited number of tests were made with samples produced on the RPI time-temperature controller. These now provide the background for a more extensive metallurgical program. These initial studies included the observation of changes in the microstructure of the weld heat-affected zone due to the welding cycle, and to one additional short-time thermal treatment (2 hr at 1200° F), and the effects of these thermal treatments on the resistance of the steel to corrosion in boiling 65% nitric acid. In addition, the work covered impact tests to determine the impact strength as a function of the peak welding thermal cycle temperature and a series of rupture tests on samples which had been treated with a thermal cycle of 2400° F peak temperature.

The synthetic thermal cycles selected for treating the test specimens were those with peak temperatures of 1800, 2000, 2200, 2400, 2475 and 2500° F. Each of these cycles represents the thermal history of one specific increment of the weld heat-affected zone that occurs when welding a $1^1/_2$-in.-thick plate with a heat input of 30,000 joules per in. and no preheat.

Material for Test Specimens

The material available for this investigation was a Type 347 stainless-steel annealed bar, $^{11}/_{16}$ in. diam,

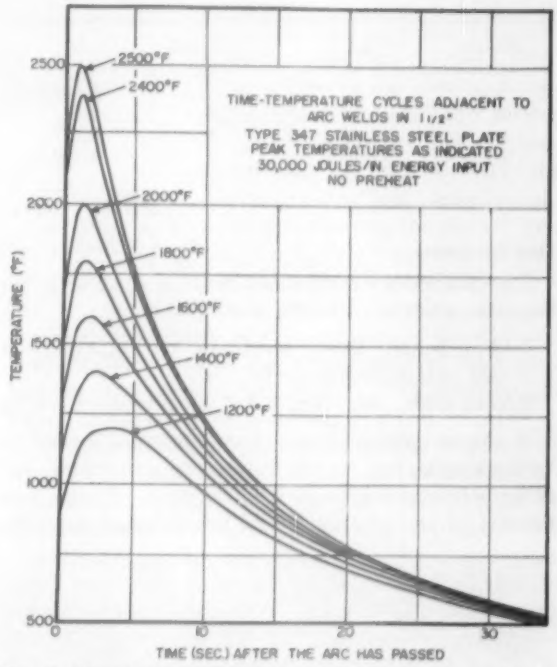


Fig. 3 Time-temperature cycles adjacent to arc welds in $1^1/_2$-in. Type 347 stainless steel

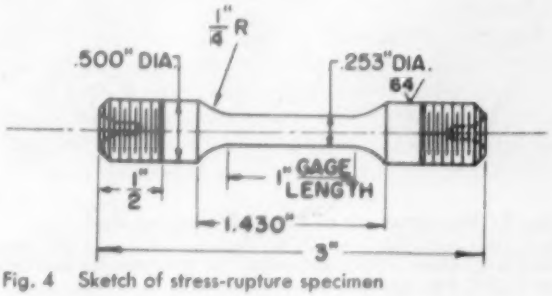


Fig. 4 Sketch of stress-rupture specimen

Table 2—Corrosion Data of Thermally Treated Specimens Subjected to Boiling 65% Nitric Acid

Thermal treatment	Corrosion rate, mils/year (48-hr test periods) 1	2	3	4	5	Avg
As-received	10.5	12.9	17.9	25.3	37.4	20.8
Thermal cycle of 2000° F peak temp	10.5	17.8	20.1	30.6	36.7	23.1
Thermal cycle of 2200° F peak temp	11.9	13.3	18.2	30.5	50	24.8
Thermal cycle of 2400° F peak temp	11.6	14.1	19.6	34.5	42.9	24.5
Thermal cycle of 2475° F peak temp	11.6	16.3	21.4	25.4	39	22.7
Thermal cycle of 2500° F peak temp	11	13.6	17.6	25.2	44.2	22.3
Thermal cycle of 1800° F peak temp, 2 hr at 1200° F	18	25	40	55	71	42
Thermal cycle of 2000° F peak temp, 2 hr at 1200° F	16	28	41	54	68	41
Thermal cycle of 2200° F peak temp, 2 hr at 1200° F	13	26	41	55	76	42
Thermal cycle of 2400° F peak temp, 2 hr at 1200° F	14	68	101	130	108	84
Thermal cycle of 2475° F peak temp, 2 hr at 1200° F	52	264	518	552	450	367
Thermal cycle of 2500° F peak temp, 2 hr at 1200° F	120	640	804	1026	862	690

which originated from heat No. 8820081 of the Allegheny-Ludlum Steel Corp. The chemical analysis of this steel was as follows:

Element	%	Element	%
C	0.08	Ta	0.23
Mn	1.53	Mo	0.06
Si	0.53	Cu	0.23
Cr	17.29	S	0.017
Ni	11.17	P	0.020
Cb	0.85		

Test Specimens

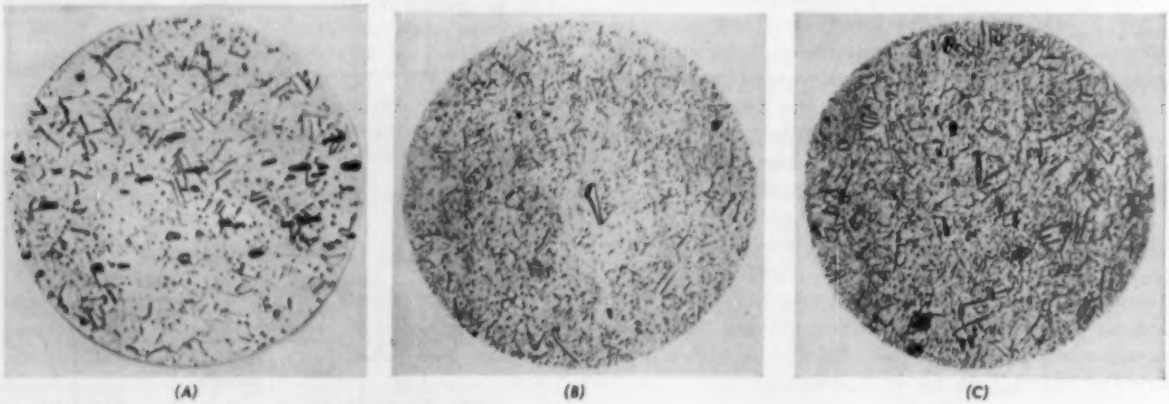
The dimensions of the specimens treated with the time-temperature controller were as follows:

0.42-in. square, 2.5-in. length for impact, corrosion and metallographic study

0.50-in.-diam, 3-in. length for stress-rupture testing

A chromel-alumel couple was percussion welded to each specimen half way from the ends into a 0.052-in.-diam hole approximately 0.05 in. deep. In the production of the synthetic weld heat-affected zone the output of this thermocouple was balanced against the signal controlled by the selected cam. Thus the heating and cooling rates simulating the welding thermal cycle were reproduced on the modified flash welder in whose water-cooled copper jaws the specimen was clamped. The maximum distance between jaws which still gave a uniform microstructure along the critical test section of the specimens and also simulated the cooling rates was found to be 0.6 in. Under these optimum conditions, the uniform microstructure existed for only 0.3 in. in samples exposed to the highest peak temperatures.

The samples used for the metallographic study and for the investigation of the effect of a subsequent 1200° F heat treatment on the resistance to nitric-acid attack were thin slices, about 0.1 in. thick, cut longitudinally from the 0.42-in.-square samples. They were trimmed to 1.2 in. length, and the surfaces were smoothed to a fine finish. The impact test bars were standard Charpy V-notch specimens. The stress-rupture bars were designed with a short gage length (Fig. 4) so that fracture would occur in the region of uniform microstructure.



(A) (B) (C)

Fig. 5 Microstructures of Type 347 stainless steel

As-received and a region subjected to a simulated weld thermal cycle with and without postweld heat treatment. Etchant, mixed acids. X 500. (Reduced 40% in reproduction.) (A) As-received. (B) After simulated weld cycle (peak temperature 2000° F). (C) Same as (B) plus a postweld heat treatment 1200° F for 2 hr.

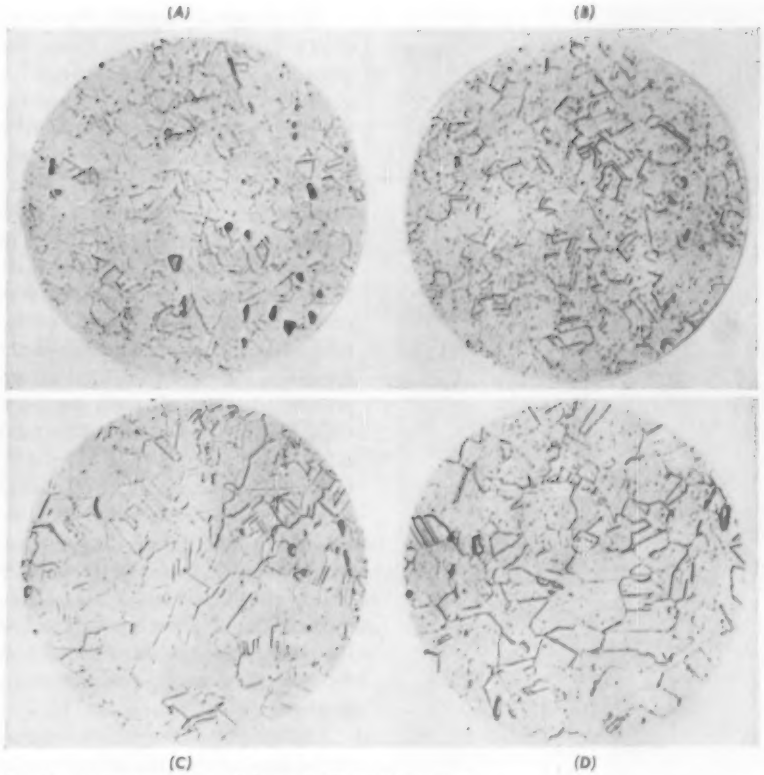


Fig. 6 Microstructures of Type 347 stainless steel

Regions subjected to simulated weld thermal cycles with and without postweld heat treatment. Etchant, mixed acids. X 500. (Reduced 40% in reproduction.) (A) After simulated weld cycle. (Peak temperature 2200° F.) (B) Same as (A) plus a postweld heat treatment. 1200° F for 2 hr. (C) After simulated weld cycle. (Peak temperature 2400° F.) (D) Same as (C) plus a postweld heat treatment. 1200° F for 2 hr.

Test Results

The welding thermal cycles which were synthetically imposed upon the test specimens brought about changes in the microstructure, subtle ones at temperatures up to approximately 2400° F, and distinct changes above that temperature.

The as-received material was fine-grained with the carbide phase generally well dispersed in dot form except for a limited number of larger inclusions, Fig. 5 (*a*). No obvious change was apparent as a result of the thermal cycles with 2000 and 2200° F peak temperature Fig. 5 (*b*) and 6 (*a*).

Grain growth first became noticeable after the 2400° F treatment Fig. 6 (*c*). Considerable grain growth was produced by the thermal cycles of 2475 and 2500° F peak temperatures, Figs. 7 (*a*) and 7 (*c*), with complete disappearance of the dot carbides. The larger inclusions appeared undisturbed by the 2475° F peak temperature treatment. The higher peak temperature of 2500° F, however, changed the appearance of these inclusions.

To determine the susceptibility of the treated specimens to sensitization, one group of these specimens was given a subsequent thermal treatment at 1200° F for 2 hr. Grain boundaries, even those of the specimen subjected to the relatively low-peak temperatures of 2000 and 2200° F, were readily brought out in etching, while the identical metallographic technique delineated the grain boundaries of the as-welded specimens only faintly. The microstructures of the sensitized specimens are shown in Figs. 5 (*c*), 6 (*b*), 6 (*d*), 7 (*b*) and 7 (*d*).

A physical effect of the carbide precipitation after welding and sensitization was demonstrated by the difference in the rate of attack on the as-welded versus sensitized specimens by boiling 65% nitric acid. Each specimen after weighing was subjected to boiling 65% nitric acid for five 48-hr periods. Fresh solution was used for each 48-hr period. The weight losses were converted to mils/year penetration in accordance with the ASTM Standard Conversion.[3] The calculated corrosion rate is reported in Table 2. Figure 8, in which the corrosion data are plotted, shows that the weld heat-affected zone in the as-welded condition is not attacked by boiling 65% nitric acid; that is, the corrosion rate is independent of the peak heat-treating temperature. After sensitization, the rate of corrosion is slightly higher for samples exposed to peak temperatures of less than 2400° F. However, the rate becomes considerable as a consequence of the postweld heat treatment of the samples exposed to high peak temperatures (2400° F and above). The intergranular nature of the corrosion is evident in Fig. 9.

The effect of welding on the mechanical properties of the weld heat-affected zone was investigated by impact tests and a short series of rupture tests at 1100° F. The results of the impact tests (Fig. 10) show that there is no appreciable change of room-temperature toughness in the weld heat-affected zone of Type 347 stainless steel, except for a slight drop for the region heated around 2475° F. No impact tests on sensitized specimens were made.

Stress-rupture tests were conducted on the material in the as-received condition and on specimens which were synthetically treated with a thermal cycle of 2400° F peak temperature. Although the 2400° F peak-temperature treatment had no drastic effect on the microstructure, the ductility values, specifically the percent reduction in area measured on the 2400° F rupture specimens, were considerably below those of the as-received material (Table 3).

Discussion

Possible differences in properties between the weld heat-affected zone and the unaffected base metal are reflections of microstructural variances which are

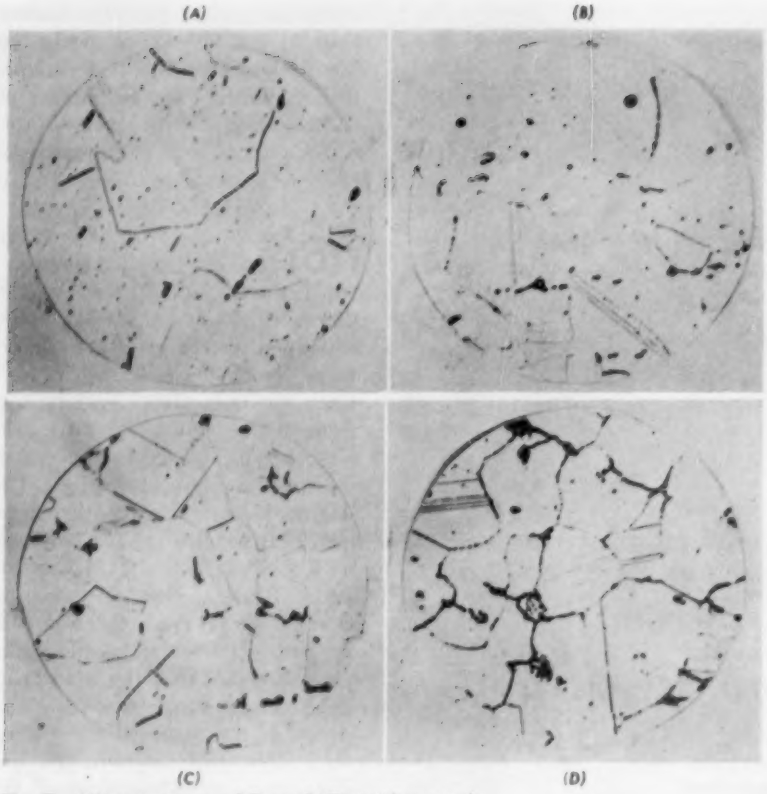


Fig. 7 Microstructures of Type 347 stainless steel

Regions subjected to simulated weld thermal cycles with and without postweld heat treatment. Etchant, mixed acids. X 500. (Reduced 40% in reproduction.) (A) After simulated weld cycle. (Peak temperature 2475° F.) (B) Same as (A) plus a postweld heat treatment. 1200° F for 2 hr. (C) After simulated weld cycle. (Peak temperature 2500° F.) (D) Same as (C) plus a postweld heat treatment. 1200 ° F for 2 hr.

caused by differences in thermal history. Although the metallurgy of the columbium-stabilized chromium-nickel austenitic steel has been studied by many investigators, the specific effects of extremely high temperatures and rapid heating and cooling rates of the order of 2500 and 300° F/sec, respectively, are not known. The intended role of columbium is the fixation of carbon from solid solution in the austenite matrix by the formation of columbium carbides.[4]

Table 3—Rupture Test* Results of Type 347 Stainless Steel at 1100° F

Load, psi	*Elongation, %*	*Reduction area, %*	*Time to fracture, hr*
	As-received		
40,000	17.8	31.1	573
40,000	18.7	33.6	553
45,000	22.2	44.0	190
45,000	22.5	44.7	292
	Weld heat-affected specimen (2400° F peak temperature)		
40,000	11.6	15.5	625
45,000	14.0	13.8	162
45,000	10.6	19.1	200

* Conducted at Watervliet Research Laboratory of the Allegheny-Ludlum Steel Corp.

The photomicrograph, Fig. 5 (*a*), shows these carbides as finely dispersed dots. These dot carbides begin to go into solution during the welding cycle in the region which reaches a peak temperature of approximately 2200° F, Fig. 6 (*a*). Complete solution of these carbides takes place at above 2400° F. The solution of these dot carbides which tend to anchor grain boundaries effects rapid grain growth, as exhibited in the microstructure of the specimen which experienced an exposure to 2475° F peak temperature, Fig. 7 (*a*). Increasing the peak temperature to 2500° F does not, however, cause any further change in grain size because incipient melting of a phase which has the appearance of an inclusion terminates grain growth, Fig. 7 (*c*). The mechanism of grain growth and of its termination as experienced here follows the rules postulated by Burke.[5]

The second phase which appears to start melting at the grain boundaries warrants special attention, since welding difficulties due to cracking in the weld heat-affected zone have been reported to be caused by just such incipient melting.[6] Dulis and Smith[7] investigated a phase which from their photomicrographs appears like the one here showing melting at the grain boundaries. They describe it as a phase which is still present in the microstructure after all of the smaller dot carbides have gone into solution. From X-ray diffraction patterns taken on a selectively etched surface, they concluded that the phase in question is both columbium carbide (CbC) and columbium nitride (CbN) presumably together in solid solution as Cb (C, N).

British research on the constitution of phases existing in columbium-stabilized austenitic steels has shown a phase other than carbides. Goldschmidt[8] finds, in addition to the columbium carbides, a phase which he terms ϕ-phase with an approximate composition of $Fe_4Cb_9Si_3$ and an appreciable solid solution field. This phase, however, was found in more complex austenitic steels with rather high carbon and silicon contents. But a tentative diagram of the Fe-Si-Cb system indicates that the ϕ-phase can occur at lower silicon and columbium contents than in the composition investigated by Goldschmidt. Binder[9] did not report the presence of this phase in 18–8 steels of lower carbon and silicon contents.

However, in the studies of the crack sensitivity of austenitic weld deposits, which for the purpose of the discussion here can be considered the solidified metal

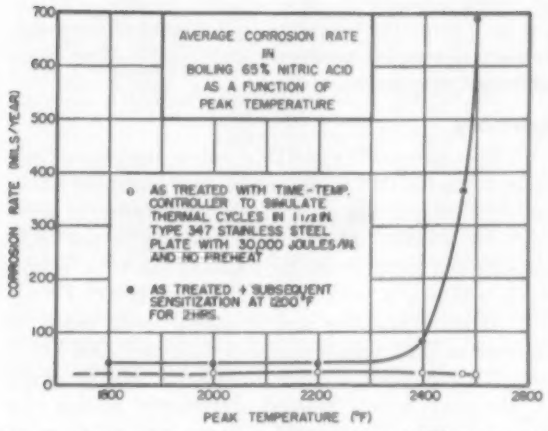


Fig. 8 Average corrosion rate in boiling 65% nitric acid as a function of peak temperature

from a molten pool, silicon was found to be a critical element. Carpenter and others[10] as well as British investigators[11] show a relationship of carbon to silicon in regard to weld cracking. Lacy and Kihlgren,[12] in their work with high nickel chromium-iron alloys, also found adverse effects of silicon on the crack resistance of weld deposits. Within the range of alloys investigated by them, they established the necessity of a columbium-silicon ratio. All this previous research and practical experience illustrate the importance of establishing the composition of the phase which appears to melt at the grain boundaries so that its formation can possibly be inhibited through a correct balance of alloying elements.

The effect of exposure to elevated temperatures on the microstructures of the weld heat-affected zone is exemplified by a study of structural changes following a 2-hr thermal treatment at 1200° F. The brief time at a peak temperature up to 2200° F produces a subtle change at the grain boundaries which are poorly defined. The subsequent 1200° F thermal treatment, however, causes the grain boundaries to be readily defined. This is observable by comparing Fig. 6 (*c*) with Fig. 6 (*d*), and Fig. 7 (*a*) with Fig. 7 (*b*). The 1200° F postweld treatment on the sample subjected to 2400° F peak temperature appears to have produced a better definition of grain boundaries, comparing Fig. 6 (*c*) and Fig. 6 (*d*), although the important over-all effect is the beginning of grain growth.

The grain-boundary precipitate becomes of considerable magnitude in the postweld-treated sample which experienced peak temperatures of 2475° F, Fig. 7 (*b*), and 2500° F, Fig. 7 (*d*). To determine whether any physical significance is associated with the appearance of this precipitate, the boiling 65% nitric-acid test was conducted. The rate of attack on the as-welded specimens was low, irrespective of the peak temperatures involved. The 1200° F postweld treatment caused little change in the rate of attack on the samples which were treated to peak temperatures of less than 2400° F. However, the 1200° F postweld treatment on

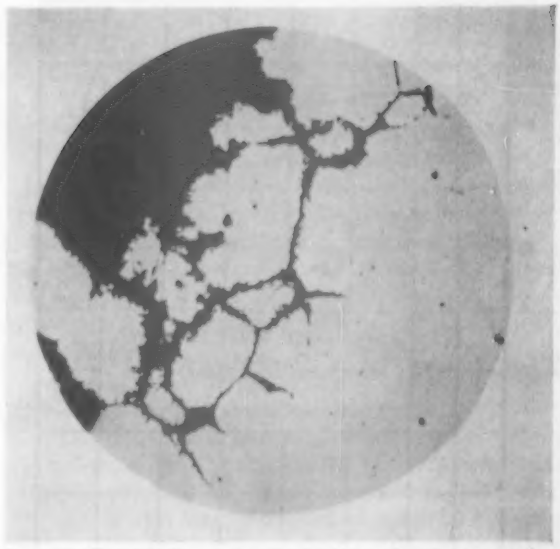


Fig. 9 Corroded specimen showing the intergranular nature of the attack. As-polished. X 500

samples which had experienced peak temperatures above 2400° F caused severe susceptibility to intergranular corrosion, Fig. 8.

The region of the weld heat-affected zone which experiences these high peak temperatures of 2400° F and above is quite narrow. In a $1^1/_2$-in.-thick plate welded with an energy input of 30,000 joules per in., this region is confined to approximately 0.05 in. from the weld bead. Therefore, this particular test can be considered a demonstration of the so-called knife-line attack which may take place under certain circumstances. Fontana[13] has described the cause of this knife-line attack by considering the destabilization of welded Type 347 stainless steel. Simpkinson[14] also describes the destabilization phenomenon. However, the association of a given phase with this intergranular corrosion phenomenon has been questioned by Kinzel[15] for the unstabilized chromium-nickel steels. He proposes the concept that the corrosion is not due primarily to the chemical composition of the grain boundary precipitate or to chromium depletion of the boundary area, but is due to a high degree of strain at the precipitate interface created by a lack of registry. Work by Ellinghausen[16] seems to support this point of view, since welded samples heated for 2 to 6 hr at 1300° F showed knife-line attack in boiling nitric acid, but longer exposure (24 hr) at 1300° F made the sample immune to this test because stress relieving has relaxed the stress gradient around the precipitate.

In high-temperature applications of Type 347 stainless steel, corrosion films in cracks within the weld heat-affected zone have been observed. Holmberg[17] draws attention to the similarity of these failures to stress corrosion. The study whose beginnings are reported here may throw some light on the origin and nature of this corrosion product in high-temperature failures of welded Type 347 stainless steel.

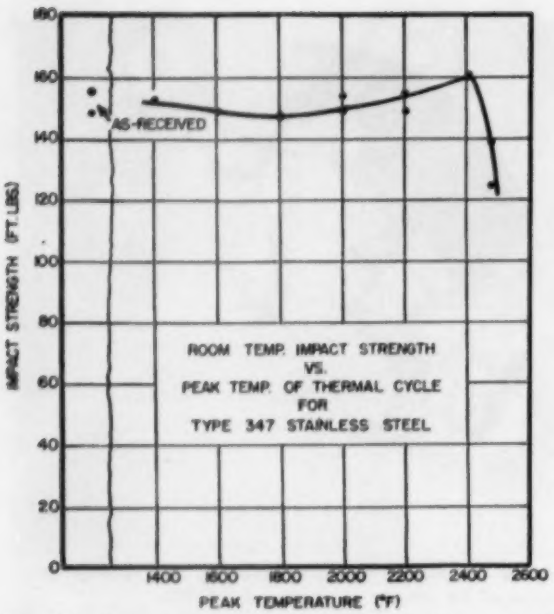


Fig. 10 Room temperature impact strength vs. peak temperature of thermal cycle for Type 347 stainless steel

The results of the impact tests, Fig. 10, conducted on samples representing regions of a weld heat-affected zone in the as-welded condition do not show much of a change as a function of welding thermal cycle. The slight drop (15%) in impact strength, for the samples heated to the high peak temperatures, is presently attributed merely to the increase in grain size.

The evaluation of the high-temperature properties of welds is frequently based upon stress-rupture tests. To obtain a pattern of the high-temperature behavior of Type 347 in the as-welded condition, samples representing the 2400° F peak temperature were tested at 1100° F. The results given in Table 3 show that the rupture ductility is considerably reduced as measured either by elongation or reduction of area. Whether the effect of the 2400° F thermal cycle on the rupture behavior is due to grain coarsening or to a precipitation phenomenon during the test at 1100° F has not been established.

In summary, the data developed in this investigation are in substantial agreement with the quoted sources. The employment of simulated time-temperature cycles based on actual thermal measurements permits temperature values to be associated with the microstructural changes occurring in the weld heat-affected zone. Thus, a means is provided for evaluating the effect of composition changes upon the narrow region, the weld heat-affected zone.

The second part of the investigation, now under way, will provide this evaluation. It covers a comparison of a fully austenitic Type 347 stainless steel with one in which certain heat treatments might cause the formation of delta ferrite. In this study the employment of controlled heating and cooling cycles is essential, and the results obtained in the initial part of this investigation have given the necessary background of the possible uses of samples produced on the RPI Time-Temperature Controller.

Summary

1. Specimens of Type 347 stainless steel have been produced on the RPI time-temperature controller which represent various regions of the weld heat-affected zone.

2. Microstructural changes occurring in the weld heat-affected zone could be followed up to a region which attained a peak temperature of 2500° F.

3. Grain coarsening and incipient fusion could be observed at peak temperatures of 2475 and 2500° F.

4. Two distinct columbium-bearing phases could be observed which reacted differently during the welding cycle. Dot carbides went into solution at temperatures below 2475° F. The other phase remained at grain boundaries and showed definite signs of melting at 2500° F.

5. Knife-line attack (in boiling 65% nitric acid) occurred only in those regions which were heated to above 2400° F.

6. The room-temperature impact strength of the heat-affected zone in the as-welded condition is not appreciably different from that of the base metal.

7. The rupture strength of the region heated to 2400° F peak temperature was investigated. This region of the heat-affected zone shows a considerable loss in ductility.

Acknowledgment

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APPENDIX

A generalized expression employing the thermal data from the oscillograph of weld runs was developed by Nippes, Merrill and Savage.[3] It is based on a series of differential equations expressing the temperature distribution adjacent to arc welds as a function of time, distance from the weld centerline and welding variables, heat input and preheat temperature. These equations have the general form

$$T - T_0 = \frac{F(s, d)}{1000} \times \text{energy input} \times \text{preheat factor}$$

where

T_0 = temperature in ° F of a point of distance, d, from the weld centerline at time, s.
T = initial plate temperature, ° F.
$F(s, d)$ = function of distance, d, from the weld centerline and of time, s, after the arc passes the location.
Energy input = weld energy input, joules/in.
Preheat factor = a multiplying factor which accounts for the effect of preheat temperatures. The value of this factor is unity at 72° F and less than unity for plate temperatures above room temperature.

The graphical solution of the differential equation involves plotting the $F(s, d)$ values for constant times as a function of distance, d, from the weld centerline. Figure 11 shows such a plot of the experimental data at 5 and 20 sec obtained from all the weld runs made without preheat.

Just as the $F(s, d)$ values in Fig. 11 exhibited some spread, so did the data from all the other weld runs. Therefore they had to be normalized, first by tabulating the values for $F(s, d)$ as a function of time and distance from experimental curves such as those shown in Fig. 11. These data were then used to plot $F(s, d)$ versus time. By replotting $F(s, d)$ versus distance for specific times and versus time for various distances, slight corrections were made to the preliminary $F(s, d)$ values.

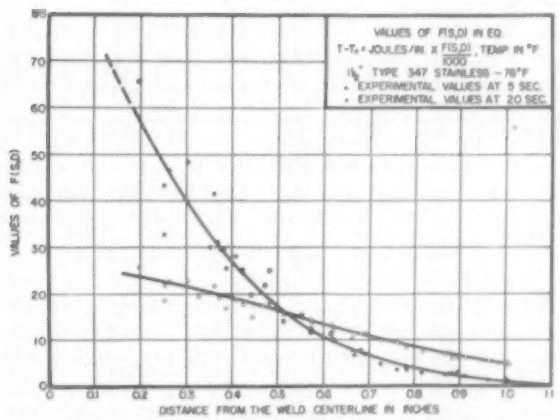
VALUES OF F(S,D) IN EQ.
T-T₀ = JOULES/IN. x F(S,D)/1000, TEMP IN °F
1½" TYPE 347 STAINLESS – 70°F
• EXPERIMENTAL VALUES AT 5 SEC.
• EXPERIMENTAL VALUES AT 20 SEC.
VALUES OF F(S,D)
DISTANCE FROM THE WELD CENTERLINE IN INCHES

Fig. 11 Experimental curves of $F(s, d)$ vs. distance from weld centerline

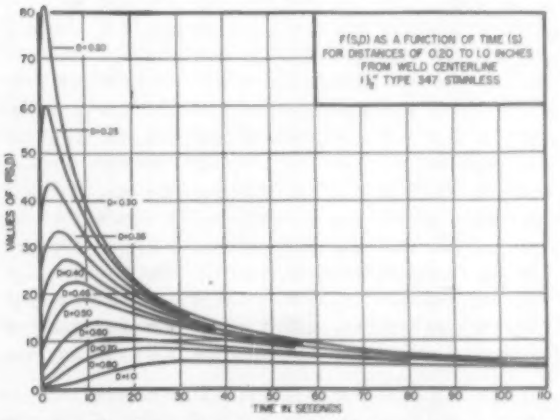

Fig. 12 $F(s, d)$ as a function of time (s) for distances of 0.20 to 1.0 in. from weld centerline

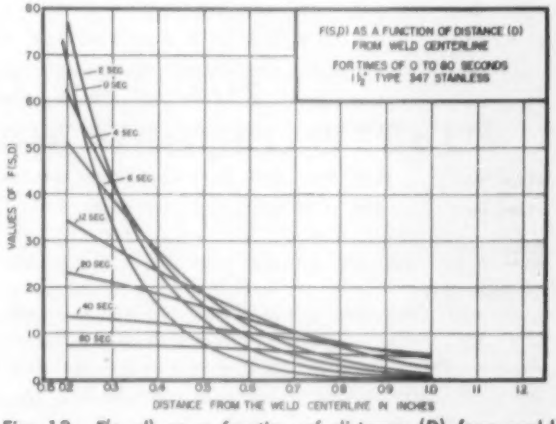

Fig. 13 $F(s, d)$ as a function of distance (D) from weld centerline

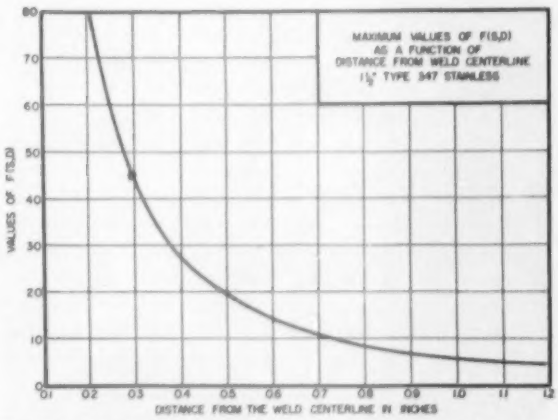
MAXIMUM VALUES OF F(S,D)
AS A FUNCTION OF
DISTANCE FROM WELD CENTERLINE
1½" TYPE 347 STAINLESS
VALUES OF F(S,D)
DISTANCE FROM THE WELD CENTERLINE IN INCHES

Fig. 14 Maximum values of $F(s, d)$ as a function of distance from weld centerline

Table 4

VALUES OF F (s, d) IN EQUATION $(T_1-T_0) = F(s,d)\frac{\text{JOULES/IN.}}{1000}$ (Temp.,° F, Distance, in.)

1/2 Inch Type 347 Stainless Steel Plate Initially at 80° F

Distance from Centerline, in. →	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38
Time, sec																			
0	68.50	63.85	59.90	55.40	51.70	48.00	44.60	41.45	38.50	35.70	33.15	30.80	28.65	26.70	24.85	23.10	21.50	20.00	18.70
1	81.30	76.05	71.40	66.85	62.60	58.30	54.40	50.70	47.20	44.00	40.90	38.05	35.50	33.25	31.15	29.20	27.40	25.70	24.10
2	77.10	73.10	69.40	65.70	62.20	58.65	55.35	52.15	49.15	46.25	43.65	41.10	38.60	36.25	34.20	32.20	30.35	28.55	26.95
3	69.30	66.30	63.30	60.45	57.80	55.20	52.65	50.10	47.80	45.45	43.25	41.10	39.10	37.10	35.15	33.35	31.65	30.00	28.50
4	62.05	59.85	57.70	55.60	53.55	51.45	49.50	47.90	45.70	43.85	42.10	40.35	38.70	37.10	35.50	33.90	32.40	31.00	29.60
5	56.35	54.75	53.10	51.45	49.75	48.10	46.50	44.95	43.45	41.90	40.50	39.10	37.75	36.40	35.10	33.75	32.40	31.20	29.95
6	51.45	50.20	48.90	47.65	46.30	45.00	43.70	42.40	41.20	40.00	38.80	37.60	36.40	35.20	34.05	32.90	31.80	30.70	29.60
8	44.10	43.25	42.40	41.50	40.65	39.75	38.85	37.95	37.05	36.15	35.25	34.35	33.45	32.60	31.70	30.85	30.02	29.20	28.40
12	34.35	33.90	33.40	32.90	32.40	31.85	31.30	30.75	30.15	29.55	28.90	28.30	27.70	27.15	26.60	26.05	25.50	25.00	24.50
16	27.90	27.65	27.40	27.10	26.75	26.40	26.10	25.72	25.35	24.95	24.54	24.15	23.75	23.35	22.95	22.55	22.20	21.80	21.45
20	23.35	23.20	23.05	22.90	22.70	22.50	22.30	22.02	21.85	21.60	21.35	21.10	20.85	20.60	20.30	20.02	19.75	19.45	19.20
28	17.85	17.80	17.75	17.70	17.60	17.50	17.40	17.30	17.20	17.10	16.95	16.82	16.70	16.60	16.40	16.25	16.10	15.95	15.80
32	16.10	16.05	16.00	15.95	15.90	15.80	15.75	15.65	15.57	15.45	15.40	15.30	15.20	15.10	15.00	14.85	14.75	14.62	14.50
40	13.62	13.59	13.54	13.50	13.45	13.39	13.33	13.28	13.21	13.15	13.10	13.02	12.95	12.89	12.81	12.73	12.67	12.59	12.50
50	11.42	11.40	11.35	11.32	11.30	11.25	11.21	11.18	11.14	11.10	11.05	11.00	10.96	10.92	10.88	10.82	10.79	10.74	10.70
60	9.70	9.68	9.66	9.62	9.60	9.58	9.56	9.52	9.50	9.47	9.44	9.41	9.39	9.35	9.31	9.29	9.25	9.21	9.19
70	8.50	8.47	8.45	8.42	8.41	8.40	8.39	8.37	8.34	8.32	8.31	8.30	8.28	8.25	8.22	8.20	8.18	8.15	8.12
80	7.63	7.62	7.61	7.60	7.59	7.58	7.55	7.53	7.52	7.50	7.49	7.48	7.46	7.44	7.42	7.40	7.39	7.38	7.36
100	6.59	6.57	6.55	6.52	6.51	6.50	6.48	6.46	6.45	6.42	6.41	6.40	6.38	6.36	6.33	6.32	6.31	6.30	6.29
120	5.80	5.78	5.75	5.74	5.72	5.72	5.71	5.70	5.70	5.70	5.69	5.68	5.67	5.65	5.63	5.62	5.61	5.60	5.60
150	4.95	4.93	4.92	4.91	4.90	4.90	4.90	4.90	4.89	4.88	4.87	4.86	4.85	4.84	4.82	4.82	4.81	4.81	4.80
180	4.40	4.39	4.38	4.38	4.37	4.36	4.35	4.34	4.33	4.32	4.31	4.31	4.30	4.30	4.30	4.29	4.29	4.28	4.27
F(s,d) max	81.50	76.80	72.15	67.80	63.40	59.40	55.60	52.20	49.10	46.30	43.80	41.45	39.30	37.37	35.50	33.85	32.42	31.10	29.82
at Time, sec	1.20	1.25	1.37	1.45	1.57	1.6*	1.78	1.88	2.02	2.20	2.40	2.70	3.00	3.35	3.68	4.00	4.35	4.62	4.96

Distance from Centerline, in.	0.39	0.40	0.41	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.60	0.70	0.80	0.90	1.00
Time, sec																						
0	17.40	16.25	15.15	14.10	13.10	12.20	11.30	10.55	9.80	9.10	8.50	7.85	7.30	6.75	6.25	5.80	5.40	3.90	2.00	1.00	0.60	0.40
1	20.55	21.10	19.70	18.40	17.20	16.05	15.00	14.05	13.10	12.20	11.40	10.60	9.90	9.20	8.60	8.05	7.50	5.30	2.70	1.40	0.80	0.50
2	25.35	23.90	22.55	21.20	19.95	18.75	17.55	16.45	15.50	14.55	13.65	12.90	12.00	11.20	10.50	9.85	9.20	6.70	3.50	1.80	1.10	0.60
3	27.05	25.70	24.35	23.10	21.90	20.75	19.60	18.55	17.50	16.50	15.60	14.70	13.85	13.05	12.35	11.60	10.95	8.10	4.40	2.40	1.40	0.80
4	28.80	26.90	25.65	24.45	23.30	22.20	21.15	20.10	19.15	18.20	17.30	16.40	15.60	14.80	14.05	13.30	12.55	9.45	5.40	3.20	1.80	0.90
5	28.80	27.60	26.50	25.35	24.30	23.25	22.20	21.30	20.35	19.45	18.60	17.70	16.90	16.10	15.30	14.55	13.85	10.80	6.50	3.80	2.20	1.10
6	28.60	27.57	26.55	25.50	24.60	23.70	22.80	21.95	21.10	20.20	19.40	18.60	17.80	17.10	16.35	15.60	14.95	12.00	7.50	4.50	2.60	1.35
8	27.60	26.75	26.00	25.80	24.60	23.70	22.95	22.20	21.50	20.80	20.10	19.45	18.80	18.20	17.60	17.00	16.40	13.65	8.95	5.60	3.50	1.85
12	24.00	23.50	23.00	22.50	22.00	21.50	21.02	20.55	20.05	19.60	19.15	18.70	18.25	17.80	17.40	16.95	16.50	14.40	10.40	7.40	4.80	3.00
16	21.10	20.70	20.35	20.00	19.60	19.25	18.90	18.55	18.15	17.80	17.45	17.10	16.70	16.40	16.00	15.65	15.35	13.70	10.80	8.00	5.80	4.10
20	18.90	18.65	18.40	18.10	17.80	17.50	17.20	16.95	16.65	16.35	16.10	15.80	15.53	15.25	15.00	14.70	14.42	13.05	10.60	8.40	6.45	4.95
28	15.60	15.45	15.30	15.15	14.96	14.80	14.60	14.45	14.30	14.10	13.90	13.75	13.60	13.40	13.20	13.00	12.80	11.80	10.00	8.40	7.00	5.70
32	14.38	14.25	14.10	13.97	13.85	13.70	13.55	13.44	13.30	13.15	13.00	12.85	12.70	12.60	12.45	12.25	12.10	11.30	9.65	8.20	6.90	5.80
40	12.45	12.35	12.25	12.10	12.10	12.00	11.90	11.80	11.70	11.60	11.50	11.39	11.29	11.18	11.07	10.94	10.82	10.24	9.00	7.80	6.70	5.70
50	10.64	10.59	10.51	10.46	10.40	10.33	10.28	10.20	10.13	10.06	9.99	9.91	9.82	9.74	9.68	9.60	9.50	9.10	8.19	7.30	6.41	5.60
60	9.15	9.11	9.06	9.03	8.99	8.93	8.90	8.87	8.82	8.76	8.73	8.69	8.64	8.59	8.52	8.47	8.40	8.20	7.43	6.75	6.14	5.50
70	8.10	8.07	8.02	8.00	7.96	7.94	7.91	7.88	7.84	7.81	7.78	7.73	7.70	7.66	7.61	7.57	7.51	7.39	6.77	6.24	5.80	5.40
80	7.33	7.31	7.29	7.27	7.25	7.21	7.19	7.17	7.13	7.10	7.00	7.05	7.01	6.99	6.95	6.91	6.88	6.70	6.26	5.73	5.50	5.20
100	6.28	6.25	6.25	6.20	6.21	6.20	6.19	6.17	6.15	6.13	6.12	6.10	6.08	6.05	6.02	6.00	5.98	5.83	5.55	5.25	5.00	4.80
120	5.50	5.58	5.56	5.54	5.52	5.51	5.50	5.49	5.48	5.47	5.46	5.44	5.42	5.40	5.39	5.37	5.35	5.25	5.02	4.76	4.60	4.45
150	4.80	4.80	4.79	4.78	4.78	4.77	4.75	4.75	4.73	4.72	4.70	4.70	4.69	4.68	4.65	4.64	4.62	4.54	4.31	4.22	4.13	4.05
180	4.26	4.25	4.24	4.22	4.21	4.21	4.20	4.20	4.20	4.19	4.19	4.18	4.18	4.17	4.16	4.14	4.12	4.08	3.99	3.82	3.72	3.62
F(s,d) max	28.70	27.60	26.60	25.70	24.75	23.90	23.05	22.25	21.50	20.80	20.15	19.50	18.95	18.40	17.80	17.30	16.80	14.42	10.77	8.50	7.00	5.85
at Time, sec	5.25	5.58	5.83	6.17	6.45	6.80	7.12	7.40	7.65	7.95	8.20	8.50	8.70	8.95	9.20	9.42	9.70	10.95	15.90	23.40	30.30	36.60

Table 4 gives the average values of $F(s, d)$, which are shown graphically in Fig. 12 as $F(s, d)$ versus time and in Fig. 13 as $F(s, d)$ versus distance.

The data tabulated in Table 4 are used to calculate for a specific peak temperature the heating and cooling cycle to which the corresponding point in the weld heat-affected zone is subjected. Such a thermal cycle is then used to construct a cam which controls the output of the RPI time-temperature controller. (For a complete description of the RPI time-temperature controller, see References 1 and 2.) The maximum values of the term $F(s, d)$ with their associated times are given at the bottom of Table 4. The shape of the curve $F(s, d)$ max versus distance from weld centerline is shown in Fig. 14.

The thermal data obtained from weld runs on the preheated plate were processed in an identical manner. Finally, the data of the preheat and nonpreheat runs were interpolated and extrapolated to determine the preheat factor. This factor makes possible the calculation of the weld thermal cycles for various plate temperatures (Table 5).

Table 5—Preheat Factors

Initial plate temperature, °F	*Preheat factor*
32	1.01
80	1.00
190	0.97
300	0.94
400	0.92
500	0.89

STUDIES ON THE BIAXIAL FATIGUE PROPERTIES OF PRESSURE VESSEL STEELS

DISCUSSION by J. T. TUCKER, JR.

The authors are to be congratulated on the fine presentation and interpretation of their high strain range fatigue data which compares the high-strength steels to some of the more conventional steels used in the manufacture of pressure vessels. This work is very timely as some higher strength steels are already being used by pressure vessel fabricators to satisfy special needs of industry for larger vessels working at higher and higher pressures. As this transition continues, there are many questions to be answered concerning the behavior of high-strength steels in order that the safety record of the future will be even better than that of the past. All these questions are not directed at the materials man and the designer, for it is also necessary that the welding engineer determine ways and means of welding these materials so the full realization of their high-strength properties may be used by the designer, the fabricator and the ultimate customer.

Pressure vessels being a major component of my company's product make us vitally concerned with all phases of pressure vessel design. Therefore our purpose in adding a discussion to this paper is to include some additional biaxial data on other steels to supplement those already presented and to show a comparison of biaxial data with uniaxial data.

Our biaxial data were obtained from flat plate specimens cycled on the hydraulic fatigue testing machine shown in Fig. 1. This machine consists of two biaxial

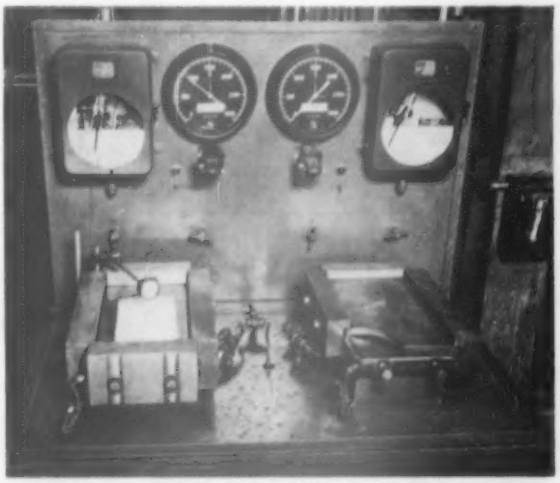

Fig. 1 General view of biaxial fatigue apparatus

Paper by Bowman and Dolan was published in the January 1955 issue of The Welding Journal, 34, Research Suppl., pp. 51-s to 59-s.

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fatigue fixtures designed at our Research Center and which, after some initial work to establish a testing method, served as the prototype for the design of the fixtures used at the University of Illinois. A complete description of our apparatus and its operation was presented before the AMERICAN WELDING SOCIETY in 1951[1] and therefore will not be discussed here.

The uniaxial data were obtained from cantilever specimens of the type shown beside the flat plate specimen in Fig. 2. The cantilever specimen has a tapered gage length which is designed as a constant strength beam giving an appreciable area under a uniform stress. An SR-4 strain gage analysis on the gage length showed the transverse strains were 0.3 the longitudinal strains indicating the uniaxiality of the stresses imposed. A cantilever bending fixture on a constant force Sonntag Universal Fatigue Testing Machine was used to cycle these specimens in complete reversal of stress at 1800 cpm. Because of the high strain range required, it was necessary to cool the specimens to maintain a constant

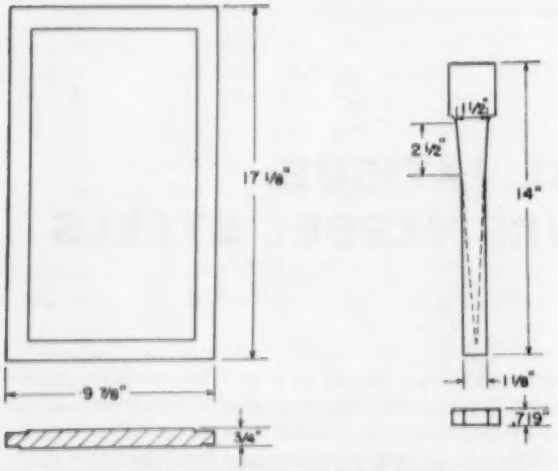

Fig. 2 Details of biaxial and uniaxial fatigue specimens

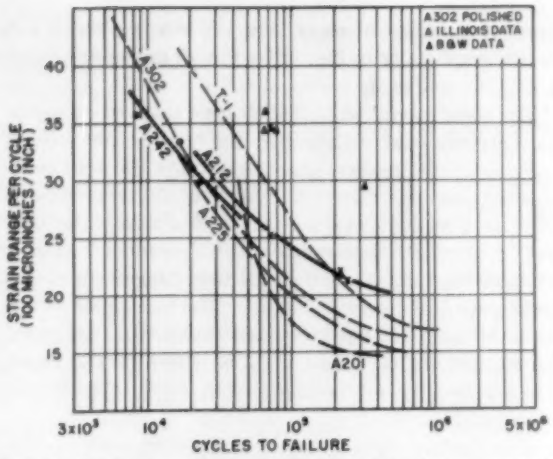

Fig. 3 Cycle comparison of biaxial data for unnotched specimens

modulus of elasticity. All biaxial specimens were cycled at approximately 30 cpm.

The three grades of $^3/_4$-in. commercial plate tested were A-212 Grade B, A-242 and A-302 Grade B. The latter steel was supplied to us from the authors' stock to check whether the similar testing methods had produced data which could be compared directly. Tables 1 and 2 list the chemical analyses and the mechanical properties of the steels before and after normalizing and stress relieving. Exactly the same procedure was followed by both laboratories in preparing specimens from these steels. In addition to the acid cleaned surface used by the authors our program included the as-received surface and a highly polished surface (5 to 7 microinch rms finish).

Our biaxial data for the A-212 and A-242 acid cleaned specimens are compared to the authors' data on Fig. 3. Also plotted on this curve are the data comparing our A-302 polished specimens with the polished specimens of the same material tested by the authors. This com-

Table 1—Mechanical Properties

	A-212		A-242		A-302	
Property	*As-received*	*As-tested**	*As-received*	*As-tested**	*As-received*	*As-tested**
Tensile	75,500	67,900	77,100	76,800	97,900	80,300
Yield	45,700	41,100	52,300	53,500	66,400	62,400
Elongation, %	35.5	36.5	30.3	29.5	25.8	30.3
Reduction of area, %	59.5	58.4	56.3	54.1	61.7	67.4
Ratio of yield to tensile	0.61	0.61	0.68	0.70	0.68	0.78

* Normalized and stress relieved.

Table 2—Chemical Analysis

Steel specification	*C*	*Mn*	*P*	*S*	*Si*	*Mo*	*Ni*	*Cr*	*Cu*
A-212	0.26	0.75	0.020	0.027	0.018	...	...	...	...
A-242	0.11	0.80	0.007	0.031	0.27	...	0.32	0.64	0.66
A-302	0.16	1.44	0.026	0.032	0.27	0.43	...	...	...

parison is very good and gives an indication that the two sets of data are directly comparable although there is a difference of 3 to 1 in cycling speed and their pressure cycle follows a square wave while ours follows a sawtooth wave. The A-212 curve indicates that its fatigue resistance at very high strain ranges is better than that for all the other materials tested with the exception of the T-1 steel, and it is apparently superior to it at the lower strain range values. However, additional data to a million cycles would be necessary to definitely establish this point. It is probably advisable that the authors test several of our A-212 plates in their fatigue machine as a further check to determine whether the comparison shown is valid or is due to some of the many variables of fatigue testing. This display of high fatigue strength by the lower tensile materials at high strain range levels is not clearly understood, but it could mean that the more ductile steels are still to be considered when increased design stresses can be used.

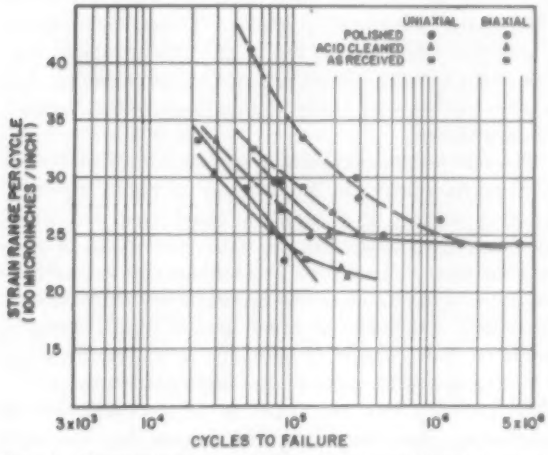

Fig. 4 Comparison of A212 uniaxial and biaxial specimens—strain basis

Any criterion common to several materials can form a basis on which these materials can be compared. The authors have used the maximum strain range per cycle as a basis of comparing the biaxial fatigue resistance of the several steels tested. However, in making a comparison between biaxial and uniaxial specimens of the same steel (A-212 Gr. B) there are other factors to be considered. It is apparent that Fig. 4, which considers only the maximum principal strain, shows the biaxial specimen at a disadvantage since no consideration is given to the strains in the other two directions. When the true stresses are calculated from the actual strain measurements they show in Fig. 5 a fairly good correlation between the uniaxial and biaxial specimens for the limited amount of data.

The true stresses were calculated on the assumption that Poisson's ratio was 0.3 since the strain hardening caused by plastic deformation was completed in the first few fatigue cycles, and the behavior of the speci-

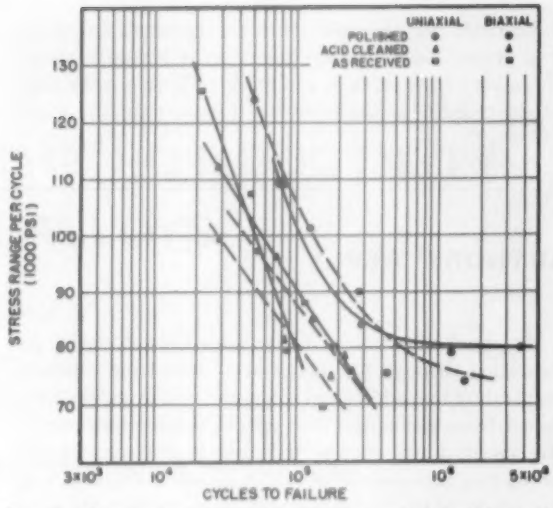

Fig. 5 Comparison of A212 uniaxial and biaxial specimens—stress basis

mens then appeared to be elastic. It is quite possible that a little plastic action was still present and that a somewhat greater value should have been used.

The comparison of biaxial data for A-212 Grade B and A-242 steel is shown in Fig. 6 for three surface conditions—polished, acid cleaned and as-received. The data show that A-212 steel has better resistance to fatigue at high strain levels than A-242 steel for all three surface conditions, notwithstanding the higher tensile properties of the A-242 steel.

The authors state that the trend toward exceptionally long fatigue life for the more ductile materials at high strain ranges is not of direct application to the design of pressure vessels because of excessive distortion. This is true for the computation of the average stresses on a vessel; however, throughout our test program we have considered the highly stressed areas on both the

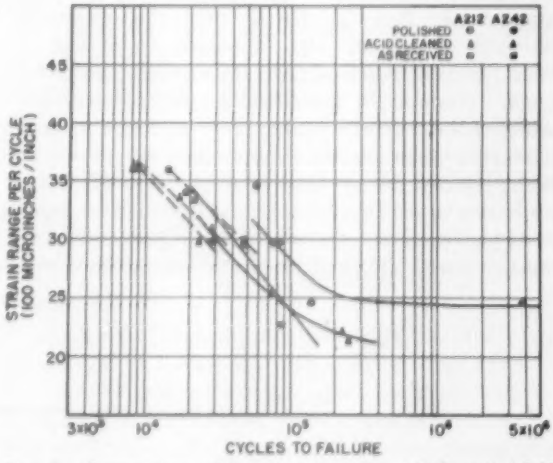

Fig. 6 Comparison of biaxial data for A212 and A242 specimens

biaxial and uniaxial specimens to represent the metal at a stress concentration point in a pressure vessel where very high stresses can exist. Therefore the high fatigue resistance displayed by the more ductile steels indicates that much higher design stresses could be allowed for these materials than are permitted by the present code.

AUTHORS' REPLY

Mr. Tucker's discussion has added much useful information through his inclusion of data from repeated load tests of two additional steels and additional data obtained from specimens with special surface treatments. His repeated load studies using bending specimens subjected to a uniaxial stress, which he has correlated with the results of the biaxial fatigue are of much interest.

The correlation between the repeated load tests of A-212 steel plate specimens and the bending specimens of that steel was excellent when the data were plotted on a graph of Stress Range per Cycle vs. Cycles to Failure. However, it appears that more work should be done to determine whether this correlation also holds for other steels and whether the limited data presented for A-212 steel in Fig. 3 are truly comparable with those of the other steels shown. These questions are raised particularly in view of the lack of close quantitative agreement between the data in the author's paper and that of Gross and Stout[2, 4] where the latter were using cantilever beam specimens and test procedure somewhat similar to that used by Tucker. Even though the relative results obtained by Gross and Stout were qualitatively similar and illustrate the same trends as obtained by the authors, there exists a considerable difference in magnitude of the cyclic strain range for a given fatigue life in each of the metals tested.

The authors still feel that it is not advisable to attach too much significance to the exceptionally long fatigue life exhibited by the more ductile metals (such as A-201 steel) at high strain ranges in the biaxial fatigue tests. It is true that the unnotched specimens exhibited remarkably high resistance to cycling at strain ranges as much as twice the nominal yield point strain. However, it should be emphasized that the nature of the test is such that at the high testing pressures very large plastic deformations are developed during the first few cycles of loading (up to 6%); i.e., in addition to the high cyclic strain, there existed superposed plastic strains that would not be permissible in a pressure vessel. These large plastic deformations were accompanied by appreciable work hardening of the steel.[3] Therefore, it seems probable that improved fatigue resistance of the *unnotched* A-201 steel plates at the high strain ranges was associated with the work hardening which would not normally be developed in an actual pressure vessel installation.

For example, a study of the *notched* specimens indicates that the greater ductility of the A-201 carbon steel was not effective in developing abnormally long fatigue life as compared with the higher strength steels when tested at high cyclic strains. Thus, in the region of a severe stress raiser, the large cyclic strain at the root of the notch probably was not accompanied by the same favorable work hardening that occurred in the unnotched plate.

The notched biaxial fatigue specimens are probably more representative of the behavior of highly stressed areas in regions of a pressure vessel near knuckles, openings, etc., than are the data from tests of unnotched plate. Therefore, the authors did not attach too much significance to the apparent tendency for the unnotched specimens of more ductile lower strength steels to show longer fatigue life at extremely high strain ranges than some of the higher strength steels. This tendency was not apparent in tests of notched specimens. However, the authors agree that the high fatigue resistance displayed by *all* of the steels is a good indication that higher design stresses could be allowed for pressure vessels than are permitted by present codes if due consideration is given to minimizing the severity of localized stresses inherent in the design.

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AN INVESTIGATION OF THE HOT DUCTILITY OF HIGH TEMPERATURE ALLOYS

A device has been developed for testing the effects of testing temperature and prior thermal history of the hot ductility of structural alloys

BY E. F. NIPPES, W. F. SAVAGE, B. J. BASTIAN, H. F. MASON AND R. M. CURRAN

ABSTRACT. The following report summarizes the details of construction of a device for determining the effects of testing temperature and prior thermal history on the hot ductility of structural alloys. The device permits subjecting suitable samples to the actual thermal cycles experienced in the heat-affected zone of an arc weld made in the alloy under study, and evaluating the influence of these thermal cycles on the hot ductility of the material.

Two grades of stainless steel, a cast and heat-treated Type 316 modified with columbium and a wrought Type 347 stainless steel have been subjected to such tests. The results indicate a significant difference in the hot-ductility of these materials. Furthermore, tests show that brief exposure to temperatures in the vicinity of 2400° F, such as would be found in the region immediately adjacent to the fusion zone of an arc weld, severely reduce the hot ductility in both grades.

It is believed that the reduction in hot-ductility and the incidence of cracking in the heat-affected zone are intimately related.

Introduction

In the manufacture of large steam turbines for the higher operating temperatures, austenitic stainless steels of the 316 Cb and 347 families have been used to a considerable degree. Welding difficulties have been experienced with these steels during such manufacture, particularly with the heavy sections utilized in turbine shell and valve components. Although such difficulties have been more frequent with cast components, the introduction of forgings in place of the castings did not result in a complete solution of the welding problem, probably because of the difficulty of obtaining enough forging to remove the cast structure completely.

Both analytical and empirical approaches to the problem were investigated by attempting to analyze the grain boundary materials through which the cracks propagated and by conducting welding tests on various castings compositions expected to be less crack sensitive. Neither approach was fruitful and it was obvious that a quantitative measure of the significant base material properties which determined its ability to be welded was needed. Since the cracking occurred during welding, the properties of these materials when subjected to the time-temperature cycle associated with the welding process were of obvious interest.

The Welding Laboratories of Rensselaer Polytechnic Institute had done considerable work in developing equipment designed to simulate the time-temperature cycle to which various points in the base metal are subjected during the welding cycle. A program was initiated to modify this equipment to permit breaking specimens at various points during the time-temperature cycle and to conduct exploratory tests to determine the usability of such equipment in measuring the properties of two austenitic materials during the welding cycle.

It was hoped that this equipment would not only provide an insight into the basic cause of and a remedy for the problems associated with welding the presently used material, but also to provide a useful tool in the development of weldable alloys which will be necessary for the higher temperature levels.

This report describes the equipment which has been developed and some of the preliminary test results which have been obtained on this equipment to date.

Object

The objects of this investigation are:

1. To study the effect of the rapid time-temperature cycles associated with arc welding on the hot-ductility of austenitic stainless steels employed in the fabrication of steam turbines.

2. To attempt to determine the mechanism responsible for hot-cracking in these steels.

Equipment

A high-speed time-temperature controller, previously constructed at RPI,[10] was used in the present study to duplicate the rapid thermal cycles associated with the heat-affected zones of arc welds. The original design was modified slightly to adapt it for use during this investigation.

Figure 1 shows a simplified schematic diagram of the

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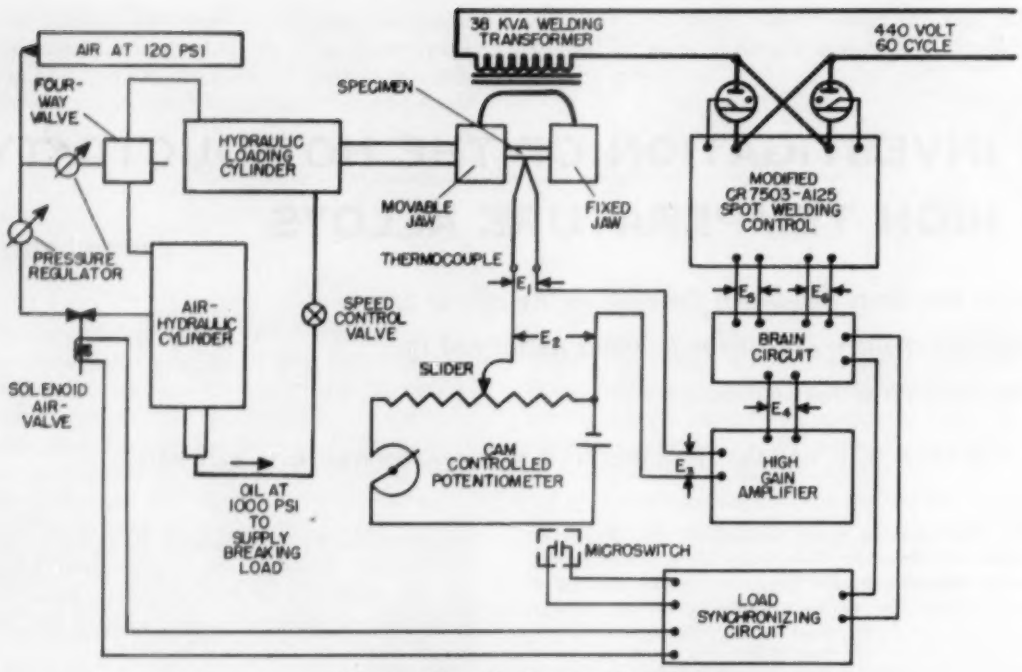

Fig. 1 Schematic diagram of hot ductility equipment

hot-ductility apparatus. The following section describes the important details of the apparatus, and summarizes the method of operation.

Electronic Control for Duplicating Desired Thermal Cycles

One fixed and one movable holding jaw, patterned after the "Templin Grips" used in tension testing apparatus, are shown in the center portion of the diagram near the top. These jaws, machined from high-conductivity Mallory 3 alloy, were employed to grip the specimen during testing, to provide electrical contact between the secondary of the power transformer and the specimen, and to extract heat from the specimen during cooling. In order to prevent heating of the jaws during the heating and cooling cycle, the design of the jaws incorporates adequate internal water cooling.

The cylindrical specimens used for this investigation were clamped in the holding jaws, as indicated in the diagram, so that a $^{13}/_{16}$-in. free length of specimen existed between the jaws. A fine wire thermocouple (0.012-in. diam Chromel-Alumel duplex) was percussion welded to the center of this free length, as shown, and provided a voltage, E_1, proportional to the instantaneous temperature of the specimen.

A specially designed, cam-operated, slide wire potentiometer, shown schematically near the center of the diagram, was employed to provide a reference voltage, E_2, proportional to the desired instantaneous temperature. By means of a simple, interchangeable, sheet-metal cam, the reference voltage, E_2, obtained from this device could be varied with time in such a way as to duplicate any desired thermal cycle.

The output voltage of the thermocouple, E_1, and the output voltage of the cam-controlled potentiometer were connected in a series bucking arrangement. In this manner, an error signal, E_3, was obtained which was proportional to the difference between the actual instantaneous temperature, as indicated by the thermocouple output, and the desired instantaneous temperature, as determined by the output of the cam-controlled potentiometer. The polarity of the error signal, E_3, of course, depended upon whether the instantaneous temperature of the specimen was higher or lower than the desired value.

The error signal, E_3, was amplified approximately 500,000 times by means of the high-gain amplifier shown at the right of the cam-controlled potentiometer. The output voltage of the amplifier, E_4, was then mixed with a suitable feedback signal, E_5, in the "Brain Circuit," shown just above the amplifier in Fig. 1. The resulting voltage, E_6, was then used in conjunction with the modified CR7503-A125 resistance welding control, shown just above the "Brain Circuit," to control the firing action of the ignitron contractor in the primary of the 38-kva resistance welding transformer.

Thus, if at any instant the temperature of the specimen was less than the desired temperature, the control circuit described above caused the ignitron contactor to conduct, energizing the resistance welding transformer primary, and, therefore, causing secondary current to flow in the specimen. The flow of this large magnitude current in the specimen caused extremely rapid heating of the free length of specimen until the desired temperature was attained. If, on the other hand, the specimen temperature at a particular instant was higher than the desired temperature, the control circuitry automatically prevented the flow of heating

current until the desired temperature was attained by extraction of heat by the water-cooled jaws.

Frequent checks of the operation of the control revealed a sensitivity of ±5° F, that is a departure of the specimen temperature from the desired temperature of 5° F was sufficient to cause the control circuitry to initiate corrective action. Additional studies indicated that the temperature distribution along the free length of the specimen varied approximately ±15° F over a 0.25-in. length centered about the location of the control thermocouple. Thus, a region 0.25 in. long and the diameter of the test specimen was subjected to the desired thermal cycle, as established by the cam-controlled potentiometer.

Loading Device for Hot Ductility Testing

Also shown in Fig. 1, are the details of the loading equipment for breaking the specimens and the associated circuitry for initiating the loading operation. The movable jaw was attached to the piston rod of a $2^1/_2$-in. diam hydraulic cylinder by means of a self aligning fitting, as shown in the diagram. Hydraulic oil at high pressure was admitted to the hydraulic cylinder through a flow control valve to load the specimen to failure. The flow control valve was calibrated to permit loading the specimen at any desired rate from 0.10 to 21.0 ips.

An air-hydraulic cylinder, which converted air pressure at 100 psi to an oil pressure of 3000 psi, was used to provide the high-pressure hydraulic fluid for loading the specimen. Loading was initiated by means of a solenoid-operated valve in the air line to the air-hydraulic cylinder, and the instant of initiation of loading was determined as follows. An adjustable microswitch, actuated by the cam-operated potentiometer mechanism, was set to close at the desired point in the thermal cycle to which the specimen was being subjected. The closing of the microswitch armed the "Load Initiating Circuit," and a feedback signal obtained from the "Brain Circuit" synchronized the loading operation, preventing the rupturing of the specimen while heating current was flowing. This precaution was necessary in order to prevent arcing from occurring and damaging the fracture surfaces. The Load Initiating Circuit, the arming microswitch and the solenoid air valve may all be seen in the labeled diagram of Fig. 1. The Load Initiating Circuit also served to shut off the control circuitry readying the hot-ductility apparatus for the next test.

Thermocouples

The thermocouples used in this investigation were manufactured from 0.012-in. diam Chromel-Alumel-duplex thermocouple wire, asbestos and glass insulated. The hot junctions were prepared by carefully cross-wire welding the two 0.012-in. diam wires in a bench-type condenser-discharge spot welder. After welding, the thermocouple was trimmed, using sharp fingernail clippers to cut directly across the center of the cross-wire weld. In this manner, a hot junction of minimum size was obtained, thus minimizing the thermal inertia of the thermocouple. This technique is vital to the successful operation of the apparatus, since improperly made thermocouples always provide erratic operation of the control equipment.

Two thermocouples were attached to the center of each specimen by a percussion welding technique, after having been inspected to make sure the hot junction was properly prepared. The most satisfactory method of testing the thermocouple-to-specimen weld was found to be a low-temperature check run of the specimen in the apparatus, and therefore a test run at 500° F was employed prior to each regular run.

Figure 2 is a photograph of the hot-ductility testing apparatus, and the following details may be seen:

1. The 38-kva resistance-welding transformer which supplies the large magnitude heating currents is visible at the right.

2. The two high-conductivity holding fixtures are visible just to the left of the transformer, connected to the transformer with heavy, flexible conductors.

3. The hydraulic cylinder, capable of producing up to 10,000-lb tensile load on the specimen, together with the associated piping and valves, is visible at the center of the supporting frame just to the left of the holding fixtures.

4. The air-hydraulic cylinder may be seen mounted vertically at the left end of the supporting frame. This device converts air pressure at 100 psi to hydraulic pressure at 3000 psi for operating the hydraulic cylinder.

Figure 3 shows a close-up of the holding fixtures. The specimen, a 0.250-in. diam cylinder, is visible between the two holding fixtures. The two fine wire thermocouples, one for control purposes, and one for monitoring, may be seen coming out of the specimen and disappearing in the foreground.

Material

Two materials were used for this investigation:

1. Type 316 Stainless Casting Alloy Modified with Cb. The analysis for the heat of Type 316 is listed below:

C, %	0.07	Mn, %	0.99
Ni, %	14.21	Si, %	0.95
Cr, %	17.65	P, %	0.020
Mo, %	2.20	S, %	0.018
Cb, %	0.49		

After casting, this material was heated uniformly to 1904–1994° F, held at this temperature for 10 hr, water cooled to 572° F, reheated to 1562–1650° F and held at this temperature for a minimum of 10 hr and then furnace cooled to 500° F.

2. Wrought Type 347 Stainless Steel. The analysis of the 347 is given below:

C, %	0.09–0.12	Mn, %	1.12
Ni, %	11.53	Si, %	0.49
Cr, %	17.85	P, %	0.020
Cb, %	0.97	S, %	0.011

This material was hot rolled, given a solution heat treatment at 1800° F, and then fast cooled.

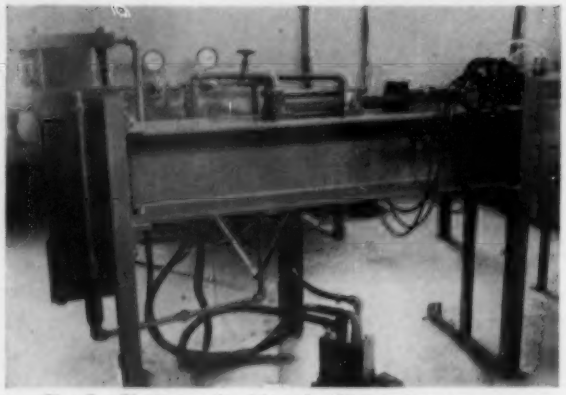

Fig. 2 Photograph of hot ductility apparatus

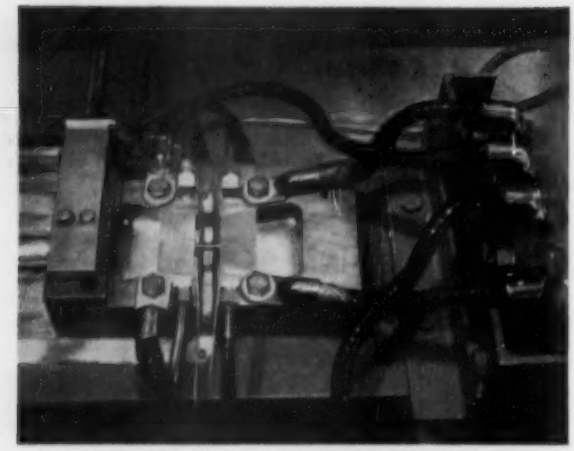

Fig. 3 Close-up of holding fixtures

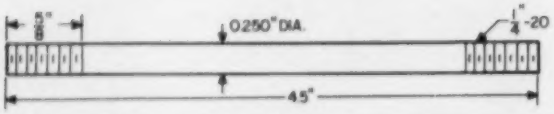

Fig. 4 Specimen used for hot ductility measurements

Figure 4 shows the dimensions of the specimens used throughout the present investigation. The specimens were ground to a finish diameter of 0.250 in., (+0.001, −0.000 in.,) and machined to 4.5-in. over-all length. The ends of the specimens were threaded to permit using stop nuts to prevent slipping in the jaws under load. The specimen diameter was the only critical dimension, and had to be maintained accurately in order to insure good electrical and thermal contact with the jaws.

Experimental Procedure

Preliminary Checking Procedure

After preparing each specimen by welding two thermocouples to the center, the specimen was gently inserted in the jaws and preloaded to insure good electrical and thermal contact between the specimen and the jaws. The preload was then removed, leaving the specimen unstressed, and the thermocouples connected. One thermocouple was connected to the control apparatus to provide the required signal proportional to the specimen temperature, as outlined previously. The other thermocouple was connected to a General Electric Photoelectric Potentiometer and the output used to drive the recording pen of an Esterline-Angus Graphic Milliammeter. In this way, it was possible to obtain a continuous record of specimen temperature throughout the testing operation.

Next, a low-temperature test run was made in which the control apparatus was set to heat the specimen rapidly to 500° F and hold it at this constant temperature. A faulty thermocouple or poor thermocouple-to-specimen weld could be detected at this point by observation of the record of specimen temperature. Hunting action on the part of the control equipment or overshooting of the 500° F test temperature were indicative of such faults, and were grounds for replacing both thermocouples. As an additional check, the bias voltage (E_b, Fig. 1) supplied the modified CR7503-A125 was observed on a cathode-ray oscillograph. By this means, an experienced operator could detect any malfunctioning of the control from the appearance of the pattern on the cathode-ray oscillograph.

The checking operation outlined above could be accomplished by an experienced operator in a matter of seconds, and was therefore adopted as standard operating procedure. By following this procedure, it was possible to obtain a consistently high percentage of satisfactory tests.

Adjustment of the Loading Mechanism

Throughout the present investigation, a loading rate of 5 ips was utilized, and the load was sustained until fracture occurred at the desired temperature. The loading operation, once adjusted, was initiated automatically, and the equipment was shut off automatically at the completion of the test. In order to adjust the temperature at which the load was applied, the position of the arming microswitch was adjusted to cause the microswitch to close when the cam follower reached a point on the cam corresponding to the desired point in the time-temperature cycle.

Testing Procedure

The evaluation of the effect of weld thermal cycles on the hot ductility of the materials studied was conducted in two parts:

1. Evaluation of the effect of the heating cycle near an arc weld on the hot ductility.
2. Evaluation of the combined effect of the heating and cooling cycle on the hot ductility.

Throughout the present investigation a single master cam was employed for the reproduction of all thermal cycles. The choice of the characteristics of this cam was based upon temperature measurements made in the heat-affected zone of arc welds in $1^1/_2$-in. stainless steel plate. The master cam decided upon had the following characteristics:

1. Rapid rise to 950° F in order to raise the specimen temperature quickly to a value equivalent to the temperature found in the plate slightly in advance of the welding arc.

Table 1—Conditions Studies in Evaluation of the Effect of the Heating Cycle on the Hot Ductility

Material—Type 316 Cb, cast and heat treated. All heating rates determined by the heating rate on the master cam (see text and Fig. 5). Loading rate, 5 ips. Specimen broken on heating cycle at indicated testing temperature

Temperature of test, ° F	*No. of specimens tested to failure*	*No. of specimens prepared —for metallographic study— Fractured specimens*	*Unbroken specimens*
1200	4	1	1
1400	5	1	1
1600	4	1	2
1800	7	1	1
1900	7	1	1
1950	5	1	1
2000	9	1	1
2050	6	1	2
2100	3	1	1
2150	5	1	1
2200	4	1	2
2300	4	1	1
2400	4	1	1

2. A constant heating rate of 240° F/sec from 950° F to a peak temperature of 2400° F. This heating rate was taken as a weighted average of the heating rates experienced in the heat-affected zone of a weld made with 70,000 joules/in. in $1^1/_2$-in. plate.

3. A cooling rate corresponding to the cooling rate just outside of the fusion zone in welds made with an energy input of 70,000 joules/in. in $1^1/_2$-in. plate.

Figure 5 shows the complete thermal cycle corresponding to the master cam. It should be emphasized at this time that none of the specimens tested experienced the full thermal cycle. Actually, the point of application of the breaking load determined at what point in the thermal cycle each specimen was broken.

Table 1 lists the conditions studied in the evaluation of the effect of the heating cycle on the hot ductility of the Type 316 Cb. Included in the table are the testing temperatures studied, the number of specimens heated to the indicated testing temperature and tested, and the number of metallographic specimens prepared for each heat treatment.

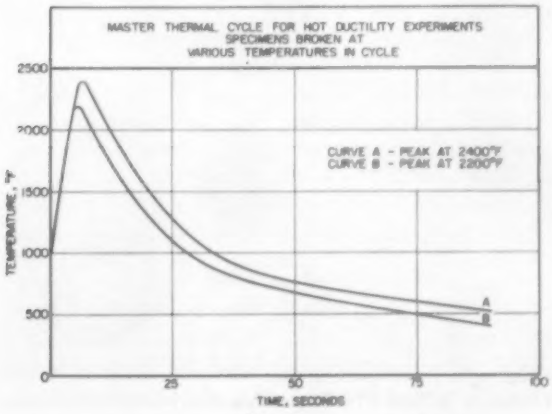

Fig. 5

Tables 2 and 3 list the conditions studied in the evaluation of the effect of the heating and cooling cycle on the hot ductility of the Type 316 Cb. Two thermal cycles differing only in peak temperatures were studied in this portion of the investigation; the heating and cooling rates being identical to those shown in Fig. 5. Table 2 shows the conditions studied with a peak temperature of 2200° F, and Table 3, those with a peak temperature of 2400° F. These tables list the peak temperature attained, the point on the cooling cycle at which the specimen was tested and the number of specimens tested.

Table 2—Conditions Studied in Evaluation of the Effect of Heating to a Peak Temperature Then Cooling to Testing Temperatures on the Hot Ductility

Material—Type 316 Cb, cast and heat treated. All heating and cooling rates determined by the heating and cooling rates on the master cam (see text and Fig. 5). Loading rate, 5 ips. Specimen broken on cooling cycle at indicated testing temperature

Peak temperature, ° F	*Temperature of test, ° F*	*No. of specimens tested to failure*	*No. of fractured specimens prepared for metallographic study*
2200	1200	3	1
2200	1400	3	1
2200	1600	3	1
2200	1800	3	1
2200	1900	3	1
2200	2000	3	1
2200	2100	3	1

Table 3—Conditions Studied in Evaluation of the Effect of Heating to a Peak Temperature Then Cooling to Testing Temperatures on the Hot Ductility

Material—Type 316 Cb, cast and heat treated. All heating and cooling rates determined by the heating and cooling rates on the master cam (see text and Fig. 5). Loading rate, 5 ips. Specimen broken on cooling cycle at indicated testing temperature

Peak Temperature, ° F	*Temperature of test, ° F*	*No. of specimens tested to failure*	*No. of fractured specimens prepared for metallographic study*
2400	1400	3	1
2400	1600	3	1
2400	1800	3	1
2400	2100	3	1
2400	2300	3	1

Table 4 lists the conditions studied in the evaluation of the effect of the heating cycle on the hot ductility of the wrought Type 347. The makeup of this table is the same as that used for Table 1.

Tables 5 and 6 list the conditions studied in the evaluation of the effect of the heating and cooling cycle on the hot ductility of the wrought Type 347. The column headings for these tables are the same as were used for Tables 2 and 3.

Table 4—Conditions Studied in Evaluation of the Effect of the Heating Cycle on the Hot Ductility

Material—Type 347, wrought. All heating rates determined by the heating rate on the master cam (see text and Fig. 5). Loading rate, 5 ips. Specimen broken on heating cycle at indicated testing temperature

Temperature of test, ° F	*No. of specimens tested to failure*	*No. of specimens prepared —for metallographic study— Fractured specimens*	*Unbroken specimens*
1200	3	1	1
1400	3	1	1
1600	3	1	1
1800	3	1	1
2000	3	1	1
2200	3	1	1
2300	3	1	1
2350	3	1	1
2400	3	1	1

Table 5—Conditions Studied in Evaluation of the Effect of Heating to a Peak Temperature Then Cooling to Testing Temperatures on the Hot Ductility

Material—Type 347, wrought. All heating and cooling rates determined by the heating and cooling rates on the master cam (see text and Fig. 5). Specimen broken on cooling cycle at indicated testing temperature

Peak temperature, ° F.	*Temperature of test, ° F*	*No. of specimens tested to failure*
2200	1200	2
2200	1400	2
2200	1600	2
2200	1800	2
2200	2000	2
2200	2100	2

Table 6—Conditions Studied in Evaluation of the Effect of Heating to a Peak Temperature Then Cooling to Testing Temperatures on the Hot Ductility

Material—Type 347, wrought. All heating and cooling rates determined by the heating and cooling rates on the master cam (see text and Fig. 5). Specimen broken on cooling cycle at indicated testing temperature

Peak Temperature, ° F	*Temperature of test, ° F*	*No. of specimens tested to failure*	*No. of fractured specimens prepared for metallographic study*
2400	1200	2	1
2400	1400	2	1
2400	1600	2	1
2400	1800	2	1
2400	2000	3	1
2400	2200	2	1
2400	2300	2	1

Method of Measuring Reduction in Area

Although the reduction in area of the wrought Type 347 stainless steel could be calculated from micrometer measurements of the reduced diameter, this technique could not be used for the cast and heat-treated Type 316 Cb. The large grain size and the residual dendritic structure present in the cast and heat-treated Type 316 Cb resulted in irregular and anisotropic deformation of the test specimen. This characteristic of the fractures in Type 316 Cb may be clearly seen by comparison of Figs. 6 and 7. Figure 6 shows photomacrographs of typical samples of the cast Type 316 Cb at a magnification of × 3.5. The irregular shape of the fracture area is clearly visible, and explains why simple micrometer measurements were inadequate for determining the reduction in area of such specimens. Figure 7 shows similar photomacrographs of specimens of the wrought Type 347 stainless steel. The fractures shown are typical of the type obtained with this material and may be seen to be nearly circular in cross section.

In order to permit accurate determination of the reduction in area, the following technique was adopted:

1. Photographs of the fractures at × 3.5 were taken with the cross-section of the specimens parallel to the photographic plate, thus providing an enlarged projected image of the fracture area on the plane of the photograph.

2. Prints of the photographs were prepared and dried by identical procedures.

3. The image of the fracture area was then cut out with sharp scissors, being careful to follow the edges of the photographic image of the fracture surface accurately.

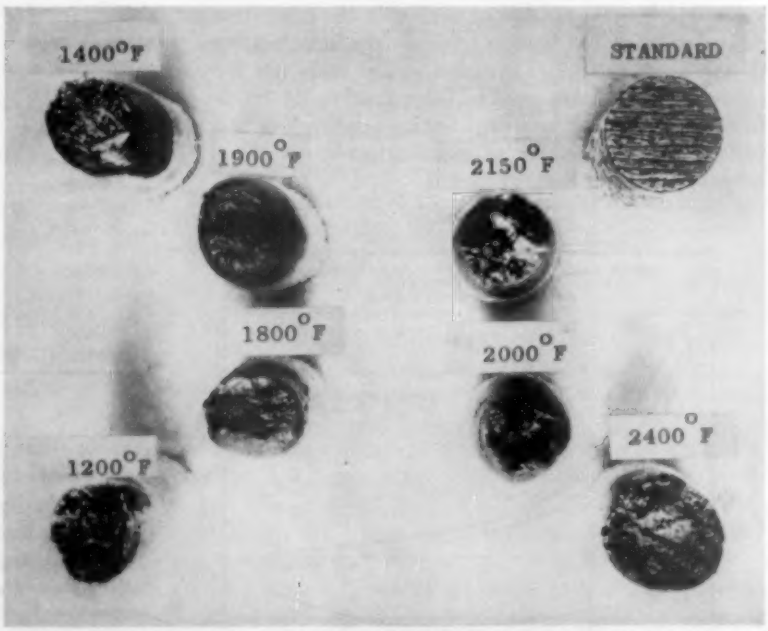

Fig. 6 Photographs of fractures in Type 316 Cb stainless steel heated to indicated temperatures. Used for reduction of area measurements. X 3.5

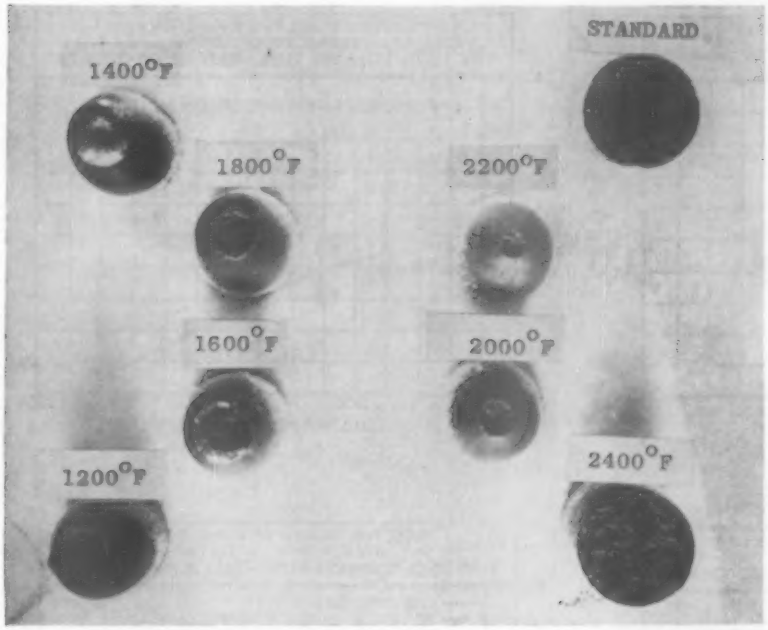

Fig. 7 Photographs of fractures in type 347 stainless steel heated to indicated temperatures. Used for reduction of area measurements. X 3.5

4. The cut-out photographic images of the projected fracture area were then stored in a desiccator.

5. The cut-out photographic images were removed from the desiccator and weighed on an analytical balance to the nearest 0.1 mg.

6. The weight of each cut-out photographic image was compared to the weight of a similar photographic image of the original cross-section of the specimen, and the reduction in area determined by the relationship:

$$\% \text{ reduction in area} = 100 \times \frac{\text{Weight of photographic image of original cross-sectional area} - \text{Weight of photographic image of projected fracture area}}{\text{Weight of photographic image of original cross-sectional area}} \quad (1)$$

The accuracy of this method was checked by comparing the data obtained by eq 1 for the specimens of Type 347 with the data obtained from the same specimens by calculation from micrometer measurements of fracture diameter. The maximum observed discrepancy found by this means was less than ±3% of the calculated value, and therefore the technique described above was adopted as standard procedure.

Preparation of Specimens for Metallographic Examination and Extraction Analysis

When the reduction of area measurements were completed, certain specimens were mounted for metallographic examination. In order to determine the nature of the constituent present at various temperatures, additional specimens were taken through a heating cycle and when a specific temperature was reached the current was turned off. The specimen was then allowed to cool to room temperature in the jaws of the machine. After it had reached room temperature, the specimen was removed from the jaws and mounted for metallographic examination.

Additional specimens were used for electrolytic extraction analysis. A conventional electrolytic extraction setup was used as shown in Fig. 8. Two different solutions were used in the electrolytic cell and the results were compared. One solution was a 10% HCl acid solution and the other was a 15% aqueous solution of ferric chloride. The purpose of this extraction technique was to concentrate the minor phases present in the specimens by dissolving away the matrix and leaving the desired phases as a residue. This residue was then collected by filtration and analyzed by X-ray diffraction techniques.

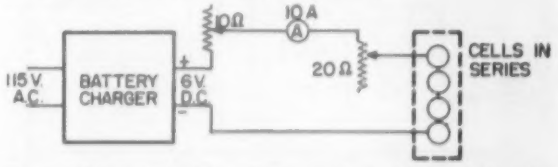

Fig. 8 Schematic wiring diagram of electrolytic extraction setup

Only the portions of the specimens subjected to the thermal cycle were used in the extraction operation. The residue which was left after the extraction was complete was dried, screened through a fine mesh screen and analyzed by two methods:

1. A portion of the residue was used as a specimen in a Straumanis-type Hull-Debye-Scherrer powder camera, giving a pattern on a strip of X-ray film. From the pattern, the diffraction angles were determined, and the interplanar spacings were calculated as an aid in the identification of the constituents present in the residue.

2. A portion of the powdered residue was sprinkled on a microscope slide and placed in a Norelco X-ray spectrometer. This equipment provided a direct record of the diffraction angles on a strip chart, and the interplanar spacings were calculated from these data as an aid in the determination of the constituents present in the residue.

Results

Hot Ductility Tests of the Cast and Heat-Treated Type 316 Cb Stainless Steel

The results of the investigation of the effect of rapid thermal cycles on the hot-ductility of the cast and heat-

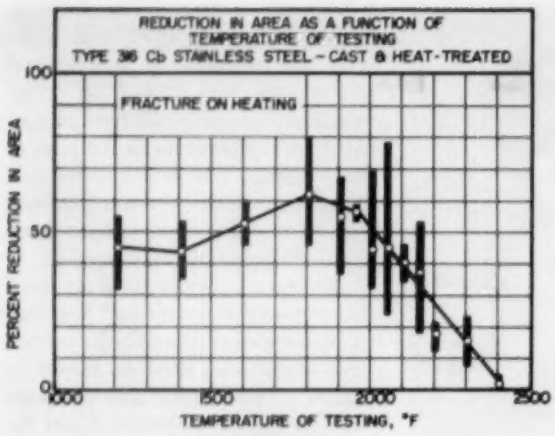

Fig. 9

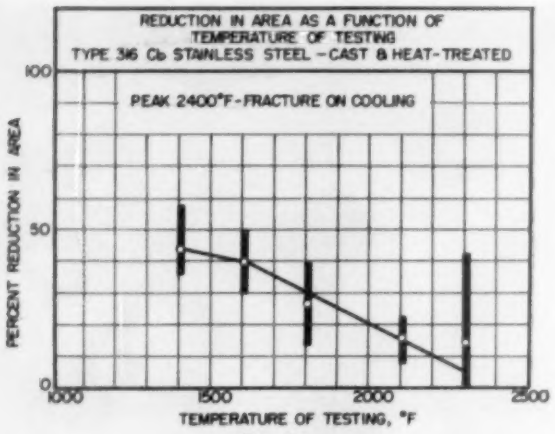

Fig. 11

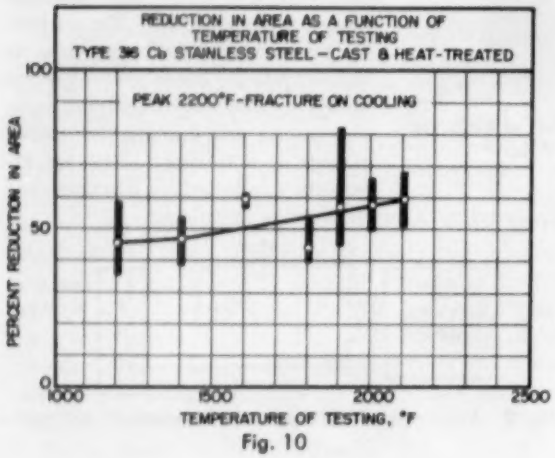

Fig. 10

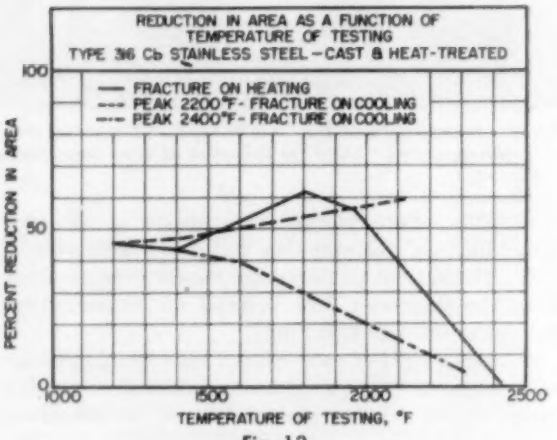

Fig. 12

treated Type 316 Cb stainless have been summarized in graphical form in Figs. 9–12. Figures 9, 10 and 11 summarize the effects of the testing procedures described previously in Tables 1, 2 and 3, respectively, and Fig. 12 was prepared by combining the individual curves shown in Figs. 9–11 in a single summary plot. In all cases, the ductility, expressed as percent reduction in area at the fracture surface, is shown as a function of the testing temperature. In Figs. 9–11, the spread in the experimentally observed values of reduction in area obtained at each testing temperature is shown by a heavy vertical bar, and the mean value of the reduction in area is shown by an open circle superimposed on the bar.

Reference to Fig. 9 reveals that the Type 316 Cb experienced an increase in ductility as the temperature of testing was increased from 1200 to 1800° F. For example, when specimens were heated from 950 to 1200° F at 240° F/sec, the mean value of the ductility was determined as 45% R. A. When specimens were heated from 950 to 1800° F at the same rate, the ductility increased to a mean value of 62%. It may be seen by further inspection of Fig. 9 that at all testing temperatures above 1800° F the ductility, as expressed by the reduction in area at the fracture, generally decreased as the testing temperature was increased. For example, when heated at 240° F/sec from 950° F, specimens tested at 2100° F showed 40% reduction in area, while those tested at 2400° F showed a mean value of 3% reduction in area.

At all temperatures investigated the fractures tended to be interdendritic in nature. Reference to the photomacrographs of fractures shown in Fig. 6, confirms this observation, since definite evidence of the interdendritic-type fracture is clearly evident even at × 3.5 in several of the fractures. The fractures were always interdendritic at temperatures above 2200° F, suggesting the existence of a low melting constituent at the dendrite interstices. The presence of such a constituent would explain the observed decrease in ductility at temperatures above 1800° F, since the strength of the constituent would be expected to decrease as the temperature neared its melting point.

Figures 10 and 11 summarize the results of the effect of the thermal cycles B and A, respectively, shown previously in Fig. 5. The specimens used in obtaining

data for Fig. 10 were heated to the peak temperature of 2200° F and cooled to the indicated testing temperature along Curve B. In preparing the specimens for obtaining Fig. 11, the same procedure was followed using Curve A which has a peak temperature of 2400° F.

The data of Fig. 10 indicate that the heating to 2200° F prior to testing has only a slight effect on the observed ductility values. Inspection of Fig. 10 indicates that following a 2200° F peak temperature the ductility tends to be higher the higher the testing temperature. The mean values of ductility observed following the 2200° F peak temperature lie within the experimentally observed spread shown in Fig. 9 at corresponding testing temperatures except for the case of tests made at 2100° F. The data for the observed ductilities at 2100° F following a 2200° F peak temperature appear to be higher than the corresponding values of ductilities shown in Fig. 9. Insufficient data are available at this time to establish whether this observation is significant, however.

The data of Fig. 11 indicate that the heating to 2400° F prior to testing significantly reduces the hot-ductility at all temperatures above 1400° F. Inspection of Fig. 11 reveals that following a peak temperature of 2400° F the ductility tends to be lower the higher the testing temperature. The observed mean values of the

Fig. 13 Type 316 Cb stainless steel heated to 1600° F and broken-unetched. X 100

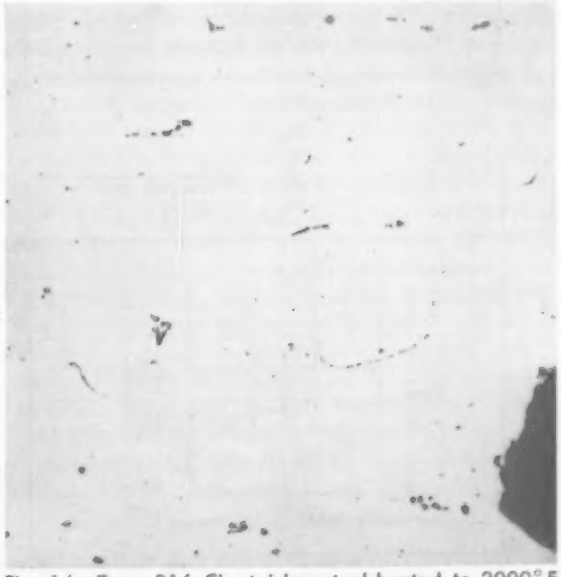

Fig. 14 Type 316 Cb stainless steel heated to 2000° F and broken-unetched. X 100

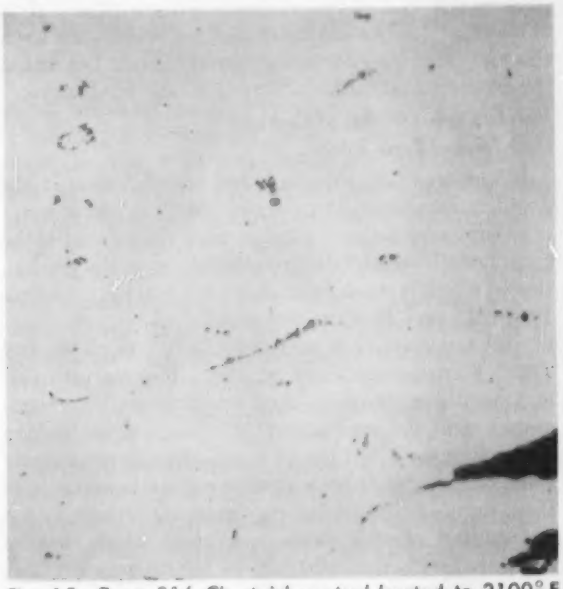

Fig. 15 Type 316 Cb stainless steel heated to 2100° F and broken-unetched. X 100

Fig. 16 Type 316 Cb stainless steel heated to 2400° F and broken-unetched. X 100

ductility after a peak temperature of 2400° F will lie below the experimentally observed spread shown in Fig. 9 at corresponding testing temperatures.

Figure 12 is a summary curve, prepared by plotting the data shown in Figs. 9, 10 and 11 on the same graph. From this figure, the reduction in the hot ductility at temperatures above 1400° F following a peak temperature of 2400° F may be clearly seen. For example, the reduction in area at 1800° F observed on heating was 62% (solid curve), while the reduction in area at 1800° F following a 2400° F peak temperature (dash-dot curve) was reduced to 30%. The reduction in area at 1800° F, following a peak temperature of 2200° F (dashed curve), lies intermediate between these values at about 54%. As was mentioned previously, however, this last value may not be significant, since it lies within the experimental spread observed for the solid curve.

Metallographic Studies of Cast and Heat-Treated Type 316Cb

It was originally proposed that the reduction in the ductility at temperatures above 1800° F was a result of either the presence of a low melting constituent at the grain boundaries and dendrite interstices, or the production of a brittle constituent at these locations. Figures 13, 14, 15 and 16 show the as-polished appearance of typical test specimens heated to 1600, 2000, 2100 and 2400° F, respectively, at × 100. The fracture surface is visible at the right-hand side of these photomicrographs, and the view shown is a longitudinal section of the specimen. Although a considerable quantity of some constituent is present at the grain boundaries of these unpolished samples, no significant change in the distribution of this phase is evident which can be associated with the difference in testing temperatures except in the case of Fig. 16. The photomicrograph, Fig. 16, showing a specimen heated to 2400° F and broken, appears to have less of the grain boundary constituent when viewed at × 100 in the as-polished condition.

Figure 17, a photomicrograph of a small area of the sample shown in Fig. 16, shows the appearance of the grain boundary constituent when viewed in the as-polished condition at × 1000. At this magnification, the grain boundary constituent visible at lower mag-

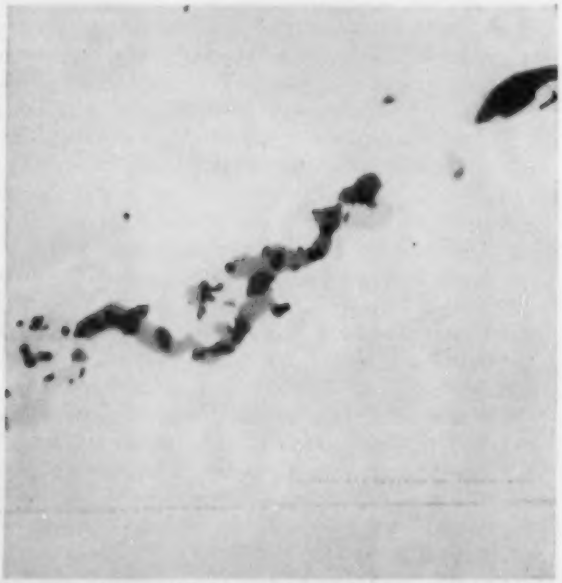

Fig. 17 Type 316 Cb stainless steel heated to 2400°F and broken-unetched. X 1000

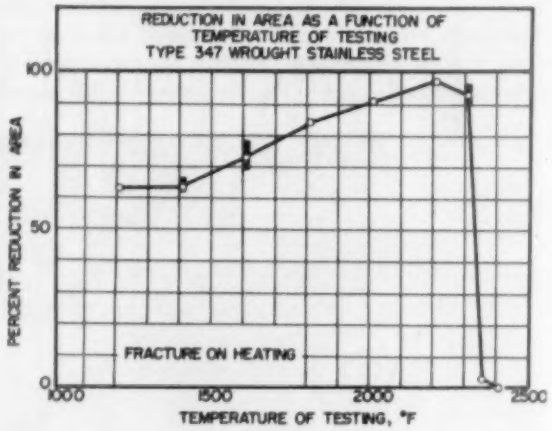

Fig. 18

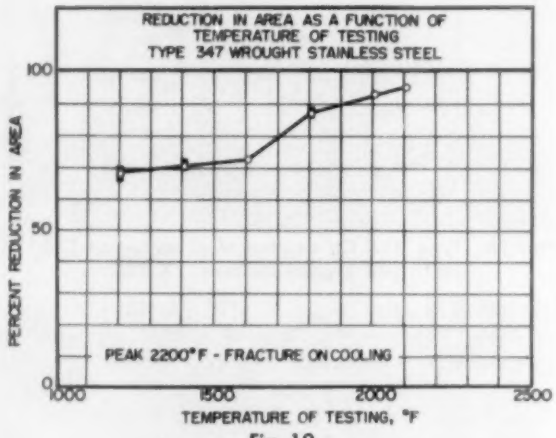

Fig. 19

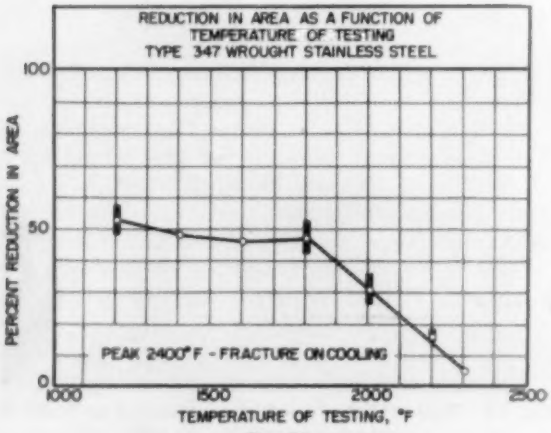

Fig. 20

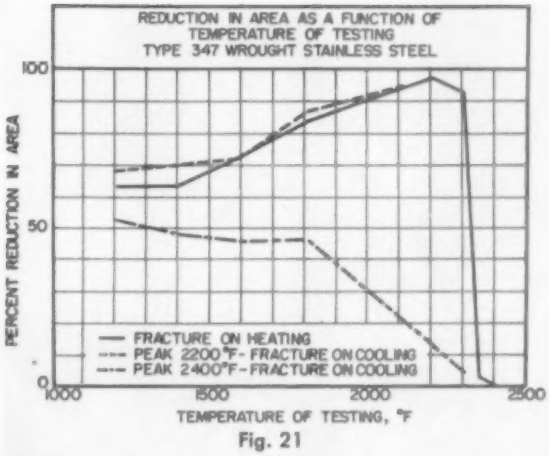

Fig. 21

nifications appears to be composed of at least three separate phases. The light-colored, angular-shaped phase appears yellow under the microscope and is believed to be columbium carbide. The gray areas and the darker areas within the gray areas have not as yet been identified.

Electrolytic separation of the grain boundary constituent and subsequent X-ray diffraction analysis have not yet led to the successful identification of these phases. The diffraction analysis has confirmed the presence of columbium carbide, but the other phases are either present in too small amounts to give diffraction patterns of usable intensity or are dissolved and lost during the extraction process.

Hot Ductility Tests of the Wrought Type 347 Stainless Steel

The results of the investigation of the effect of rapid thermal cycles on the hot-ductility of the wrought Type 347 stainless steel have been summarized in graphical form in Figs. 18–21. Figures 18, 19 and 20 summarize the effects of the testing procedures described previously in Tables 4, 5 and 6, respectively, and Fig. 21 was prepared by combining the individual curves shown in Figs. 18, 19 and 20 in a single summary plot. In all cases, the ductility, expressed as percent reduction in area at the fracture surface, is shown as a function of the testing temperature. In Figs. 18–20, the spread in the experimentally observed values of the reduction in area obtained at each testing temperature is shown by a heavy vertical bar, and the mean value of the reduction in area is shown by an open circle superimposed on the bar. Where no bar exists, the spread in observed values was smaller than the diameter of the open circle. Comparison of these data with similar data for the Type 316 Cb shown in Figs. 9–11 indicates that the data for the Type 347 was much more consistent at all values of testing temperature. This can be explained as resulting from the more isotropic behavior of the fine-grained wrought Type 347 as compared with the anisotropic behavior of the coarse-grained, cast Type 316 Cb.

Examination of Fig. 18 reveals that the ductility of the wrought Type 347 increased continuously as the testing temperature was increased from 1200 to 2200° F. For example, when specimens were heated from 950 to 1200° F at 240° F/sec., the mean value of the ductility was determined at 63% R.A. When the specimens were heated from 950 to 2200° F at the same rate, the hot-ductility was found to have increased to 97% R.A. Increasing the testing temperature to 2300° F caused a slight decrease in the mean value of the reduction in area to 93% R.A., while increasing the temperature of testing to 2350° F caused the reduction in area to diminish to 3% R.A. At a testing temperature of 2400° F, no measurable reduction in area was observed.

As was the case with the Type 316 Cb, the observed hot-ductility variations with Type 347 stainless steel suggested the existence of a low melting constituent at the grain boundaries. However, two major differences in the microstructure of the Type 347 would be expected to reduce the effectiveness of such a constituent at the grain boundaries. First, the cast structure present in the Type 316 Cb material tested was not present in the Type 347 stainless tested, having been removed by a hot working operation during manufacture. Secondly, the grain size of the Type 347 used was much smaller, thus providing a much greater grain boundary area. This would be expected to result in distributing any low melting constituent more generally throughout the specimen and make the existence of a continuous film at the grain boundaries unlikely unless a large amount of the constituent were present.

Figure 20 summarizes the results of the thermal cycle marked *B* in Fig. 5. The specimens used in obtaining data for Fig. 19 were heated to the peak temperature of 2200° F and cooled to the indicated testing temperature along Curve B. The data shown in Fig. 19 indicate that the heating prior to testing had little, if any, effect on the observed ductility values. Comparison of the data shown in Fig. 18 with that shown in Fig. 19 confirms this fact, since the curves are similar in shape and do not differ greatly at individual testing temperatures.

Figure 20 summarizes the effect of the thermal cycle marked *A* in Fig. 5. The specimens used in obtaining data for Fig. 20 were heated to the peak temperature of 2400° F and cooled to the indicated testing temperature along Curve A. The data shown in Fig. 20 indicated that heating to the peak temperature of 2400° F significantly reduced the hot ductility at all testing temperatures. Inspection of Fig. 20 reveals that the hot ductility following thermal Cycle A (Fig. 5) decreases when the testing is performed at progressively higher temperatures during the cooling portion of the cycle. The observed hot-ductility was 53% R.A. at 1200° F, 47% at 1800° F and 15% at 2200° F, as may be seen from Fig. 20.

Figure 21 is a summary curve prepared by plotting the data shown in Figs. 18, 19 and 20 on the same graph. From this plot, the reduction in the hot ductility at all testing temperatures following a peak temperature of 2400° F is clearly evident. For example, the reduc-

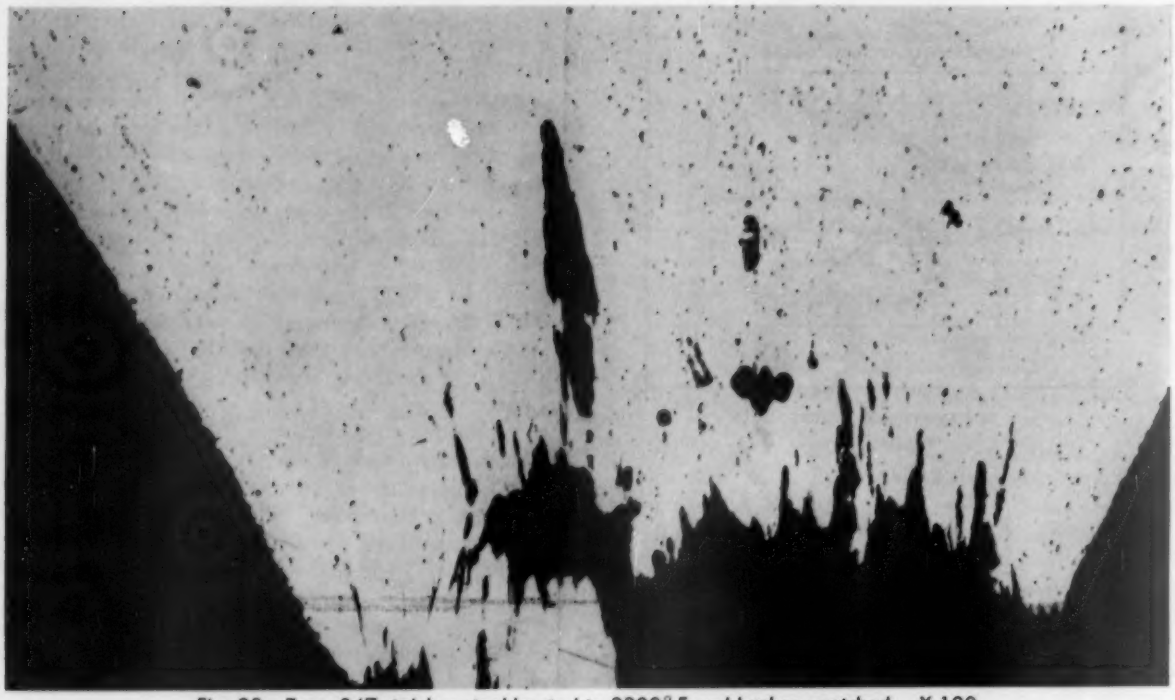

Fig. 22 Type 347 stainless steel heated to 2200° F and broken-unetched. X 100

tion in area at 2200° F observed on heating was 97% (solid curve), while the reduction in area at 2200° F observed after heating to 2400° F (dash-dot curve) was reduced to 15%. The similarity between the curves representing testing during the heating cycle (solid curve) and testing during cooling following a peak temperature of 2200° F (dashed curve) may also be seen.

Metallographic Studies of Wrought Type 347

The metallographic studies of the Type 347 are not complete at the present time. However, some interesting preliminary studies are described below. Figures 22 and 23 show the as-polished appearance of typical test specimens heated to 2200 and 2400° F, respectively, and broken. The magnification in both cases is × 100, and the appearance of the fracture is shown on these longitudinal sections of the specimen. The distribution of inclusions clearly indicates the direction of the hot-working process during manufacture, although the "necking-down" which occurred during testing of the specimen shown in Fig. 22 causes a convergence of the stringer-like rows of inclusions.

The ragged appearance of the fracture-surface shown in Fig. 22 suggests that the fracture occurred along the rows of inclusions when the testing was performed at 2200° F on the heating portion of the cycle. At one location near the fracture surface, a large elongated void may be seen which adds further support to this

Fig. 23 Type 347 stainless steel heated to 2400° F and broken-unetched. X 100

Fig. 24 Type 347 stainless steel heated to 2400°F, cooled to 2200° F and broken-unetched. X 100

theory. An indication of the extremely high ductility may be obtained from the fact that the entire cross section of the fracture surface is visible in this photomicrograph at × 100. No evidence of grain boundaries can be seen in this photomicrograph, although the inclusions are for the most part located at grain boundaries, as was revealed by examination at × 1000 magnification.

Figure 23 is typical of the appearance of specimens broken on heating at 2400° F. The undisturbed alignment of the inclusions, and the marked intergranular appearance of the fracture are evidence of the brittle nature of such specimens. In places, the tendency of the fracture to follow grain boundaries has produced secondary fractures roughly parallel to the main fracture surface. These secondary fractures obviously follow a path along a series of grain boundaries as may be seen by the numerous changes in direction of the fracture. Again, no marked evidence of grain boundaries appears in the as-polished surface of the specimen at × 100 except in those regions near the fracture surface where secondary fractures appear. The amount of the dark constituent appears to have been reduced somewhat by this thermal treatment, indicating that the solubility of the constituent is significantly increased at 2400° F, and that possibly a portion of the constituent remains in supersaturated solution due to the rapid cooling of the specimen from 2400° F after fracture.

Figure 24 shows an as-polished longitudinal section including the fracture surface of a typical sample heated to the peak temperature of 2400° F, cooled to 2200° F along Curve A (Fig. 5) and tested. The magnification, × 100, is the same as for the previous figures, and the similarity in the appearance of the fracture surface in Figs. 23 and 24 is apparent. However, some grain boundaries are evident in Fig. 24, not only near the fracture surface, but throughout the area shown. Furthermore a redistribution of the "inclusions" has obviously occurred, as may be seen by comparison of Figs. 22, 23 and 24. The amount of the dark-appearing constituent is definitely greatest in Fig. 24, least in Fig. 23 and intermediate in Fig. 22. This condition would be expected if the solubility of one or more of the phases present in the dark constituent increased with increasing temperature. A proposed mechanism is suggested below:

1. On heating, one or more of the phases in the dark constituent dissolve in the matrix. The higher the temperature, the more complete the solution.

2. If the specimen is tested on the heating cycle, a portion of the material dissolved is retained in supersaturated solid solution by the rapid cooling of the test specimen after fracture occurs. Thus, the sample tested at 2400° F on heating would show less of the dark constituent after testing than the one tested at 2200° F where less solution had occurred.

3. If the specimen is heated to a peak temperature and then cooled to the testing temperature under controlled conditions, the solution occurs, but a greater proportion of the material is rejected during the slower cooling. The reprecipitated phase or phases tend to form on the grain boundaries on cooling, thus outlining the grains.

Electrolytic extraction of the grain boundary constituent and subsequent X-ray diffraction analysis has not led to positive identification of the phases present as yet. Future work will include, in addition, etching studies as a further aid to identification, however, and it is hoped that the nature of the grain boundary constituent may be positively established.

Summary and Conclusions

The following conclusions were reached.

1. Equipment was developed which permits: (*a*) Duplication in the central portion of a suitable test specimen of the thermal cycle experienced at any desired point in an arc-weld heat-affected zone. (*b*) Subjecting the specimen to a tension test at any desired predetermined point in the above thermal cycle for the purpose of measuring the effect of the thermal cycle on the hot-ductility.

2. Two grades of stainless steel, a columbium modified Type 316 casting alloy, and a wrought Type 347 alloy, were subjected to tests in the above equipment and the effect of thermal history on the hot-ductility was evaluated by measurement of the reduction in area at fracture.

3. Both grades studied showed an intergranular type fracture and almost no ductility when heated to temperatures above 2350° F and tested.

4. The hot-ductility of the Type 347 stainless steel, measured during the heating portion of the thermal cycles studied, was far superior to that of the Type 316 Cb at testing temperatures between 1400 and 2300° F.

5. The investigation showed that the prior thermal history markedly affected the hot ductility of both grades. In general, short exposures to temperatures in the range of 2400° F caused a significant reduction in the hot-ductility measured at temperatures between 1400 and 2300° F for both grades.

6. The tests show promise of revealing significant differences in the elevated temperature properties of the base metal that may explain the observed difference in weldability.

7. The test provides a rapid means of determining the properties of base materials when subjected to actual welding cycles and should aid in determining the effects of changing base metal composition, heat treatment and other variables on weld properties.

8. An analysis of the cause of low ductility observed during the welding cycle should be facilitated by the fact that this test provides a finite volume of material for study identical to that found at a given distance from the fusion line of an actual weld.

Acknowledgments

The authors wish to acknowledge the guidance and counsel of Andrew W. Rankin, Supervisor of Turbine Structural Engineering, Turbine Division, General Electric Co.

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Supplementary Note on

CRACK-STARTER TESTS OF SHIP FRACTURE AND PROJECT STEELS

BY P. P. PUZAK, M. E. SCHUSTER AND W. S. PELLINI

In the Appendix of the subject paper the authors presented detailed information concerning the preparation of specimens and procedures for conducting crack-starter drop-weight tests. The salient features and the success of the drop-weight tests are dependent upon the development in the crack-starter weld (after only minute bending of the test specimen) of a cleavage crack. The test then evaluates the ability of the steel to deform in the presence of this crack; i.e., the steel either accepts the crack readily and breaks into two pieces, or it rejects the crack and bends the slight amount permitted in the test without complete fracturing. The test results were demonstrated to correlate to the initiation aspects of brittle fracture in service performance of the mild steel class.

As stated in the Appendix of the subject paper, all of the test data were obtained using $^5/_{16}$-in. diam. Murex Hardex 25 (a hard-surfacing electrode) for the crack-starter weld. The success obtained with such material in developing "crack-starting" conditions is readily apparent from the data contained in the various papers pertaining to crack-starter tests which have been published since 1952. Recent modifications in the Murex Hardex 25 electrodes have resulted in increased ductility in this material; thus making it unsatisfactory for crack-starter tests. A new electrode which is designated Murex Hardex N, and which corresponds to the previous material used successfully for crack-starter tests should now be obtained.

Tests of other materials have indicated that any weld bead performs satisfactorily as a "crack-starter" *if* it develops a cleavage crack at the instant that yielding occurs in the surface fibres of the test specimen. For a crack-starter material to be completely successful, it should develop cleavage fractures (as above) for all temperatures up to approximately 300° F.

Paper by P. P. Puzak, M. E. Schuster and W. S. Pellini was published in the October issue of THE WELDING JOURNAL, **33**, (10), Research Suppl., 481-s to 495-s (1954)

WELDING PROCEDURE QUALIFICATION TESTS FOR SIX HIGH-YIELD-STRENGTH STEELS

Qualification procedure tests to establish suitable welding procedures for six high-strength pressure-vessel steels

By A. P. BUNK

SUMMARY. Welding procedure qualification tests, made in accordance with Section IX of the ASME Code for Unfired Pressure Vessels, were conducted on three pairs of steels with minimum yield strength of 50,000, 70,000 and 90,000 psi, respectively. The purpose of these qualification tests was to establish suitable welding procedures which would meet the requirements of the Code.

The more important results of this study may be summarized as follows:

1. ASME Code requirements for manual welding procedure qualification can be met when E7016 electrodes are employed to weld a Mn-Mo steel without preheat, provided a postwelding heat treatment at 1150° F is applied. Code requirements are also satisfied when either E8016 (1% Ni) or E9015 (Mn-Mo) electrodes are utilized under similar conditions of no preheat and 1150° F postheat. Automatic two-pass submerged melt welds appear to be satisfactory for joining this Mn-Mo steel in the 1 in. thickness.

2. Manual welds, made with E7016 electrodes in normalized Mn-V-Ti steel without preheat, fulfill Code requirements regardless of whether or not a postwelding treatment at 1150° F is employed. Automatic two-pass submerged melt welds are suitable for welding this steel in the 1 in. thickness.

3. Manual welds, using E10016 (Ni-Mo-V) electrodes on Ni-Cu-Mo-V normalized and tempered steel of 70,000 psi minimum yield strength, meet Code requirements for procedure qualification when neither preheat nor postheat is employed. Automatic two-pass submerged melt welds also meet procedure requirements without use of preheat or postheat.

4. Manual welds, using E9015 (Mn-Mo) electrodes on hot-rolled and stress-relieved Ni-Cu-Mo steel, meet ASME Code requirements without use of preheat provided a postheat treatment of 1100° F for 1 hr is employed.

5. Quenched and tempered Mn-Cr-Ni-Mo-Cu-V steel of 90,000 psi minimum yield strength, welded with E12015 (Ni-Mo-V) electrodes using neither preheat nor postheat, did not consistently meet present Code requirements with respect to the side-bend test for overhead position welds. Side-bend specimens tested in a jig modified to accommodate a plunger of 1.25 in. radius instead of the usual 0.75 in. radius, consistently passed the test. In connection with the side-bend test and its use as a criterion of ductility, a review of the history of the test is recommended with the view of determining the circumstances surrounding adoption of present jig dimensions. Automatic two-pass submerged-melt welding of this Mn-Cr-Ni-Mo-Cu steel requires further study designed to obtain higher weld metal strength.

6. Quenched and tempered Mn-Mo (0.3% C) steel did not consistently meet present Code requirements of side-bend test for the vertical position, when manually welded with E12015 electrodes, employing a 200° F preheat and no postheat. Using a jig modified to accommodate a 1.25-in. radius plunger, all specimens passed. Comments made in Conclusion 5 regarding the side-bend test apply to this Mn-Mo (0.3% C) also. Automatic submerged-melt welds made in Steel F did not meet present ASME Code requirements. Further study of the submerged melt process for welding this Mn-Mo (0.3% C) steel is warranted.

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The tests reported herein were conducted at the Chicago Bridge & Iron Co. at the request of H. C. Boardman, Chairman of the former Welding Research Council's Weldability Subcommittee on Low-Alloy Steels.

Introduction

The Materials Division of the Pressure Vessel Research Committee has been investigating the suitability of six high-yield-strength steels for pressure vessel service for the past two years. A special Subcommittee on Research on High Strength Steels* was established for that purpose. This Subcommittee, cognizant of the dominant role which welding plays in the fabrication of any pressure vessel, included for part of its study the effect of welding upon the behavior of high-strength steels under various conditions of loading. In order to conduct such tests, it was necessary to obtain, initially, recommended procedures for welding those steels. Since the objective of the PVRC Subcommittee was, principally, to evaluate materials and not welding procedures, the Welding Research Council's Weldability Subcommittee on Low Alloy Steels† was requested to supply recommended procedures of welding.

As a starting point the WRC Subcommittee obtained recommended welding procedures from the various suppliers of the steels. The recommendations of the suppliers were then used as a basis for procedure qualifications made in accordance with Section IX of the ASME Code for Unfired Pressure Vessels.[1] The use of the ASME Code as a criterion for evaluating the weldability of steels was appropriate and logical, since the ultimate aim of PVRC was to gain recognition of these high-strength steels for pressure vessel service

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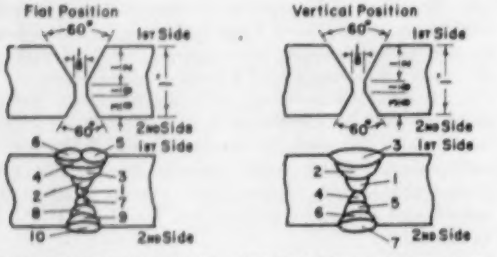
† H. C. Boardman, *Chairman;* T. N. Armstrong, L. C. Bibber, W. D. Doty, B. E. Somers, W. Spraragen and R. D. Stout.

by code-making bodies. It is inevitable that, at some time or other, those code-making bodies would inquire whether or not present code welding requirements could be met.

The purpose of this work was to determine, therefore, whether or not all position welds, made in such high-yield-strength steels, would meet the requirements of Section IX of the 1952 ASME Code for Unfired Pressure Vessels.

Description of Tests

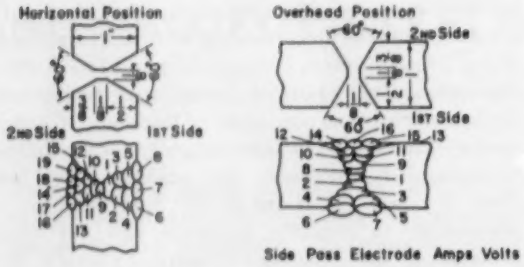
Test welds consisted of joining two plates, 6 x 1 x 18 in., along the 18-in. edge—the 18-in. edge having been previously prepared by machining to produce a joint geometry as shown in Figs. 1, 2 and 3. Each of the plates comprising the test assembly was cut so the 18-in. edge was parallel to the rolling direction.



Side	Pass	Electrode	Amps	Volts
1	1	5/32"	140	22
1	2-6	3/16"	180	22
2	7-10	3/16"	180	22

Side	Pass	Electrode	Amps	Volts
1	1-3	5/32"	150	23-25
2	4-7	5/32"	150	23-25

Fig. 1 Typical edge preparation and welding conditions for manual flat and vertical position welds

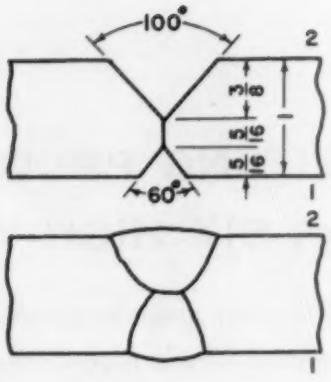


Side	Pass	Electrode	Amps	Volts
1	1-8	5/32"	150	23
2	9-19	5/32"	150	23

Side	Pass	Electrode	Amps	Volts
1	1-2	1/8"	105	25
1	3-7	5/32"	135	25
2	8-11	1/8"	105	25
2	12-16	5/32"	135	25

Fig. 2 Typical edge preparation and welding conditions for manual horizontal and overhead welds

Aside from the restraint provided by the plates, together with run-off tabs located at the ends of the joint, no additional restraint was imposed upon the assembly. For welds wherein no preheat was employed, an interpass temperature of 120° F maximum was maintained, whereas, for preheated welds, the interpass temperature was kept at the preheat temperature. The root of each weld, submerged-melt welds excepted, was carbon-arc gouged prior to depositing metal on the second side. Test bar blanks were then removed from the welded assembly by sawing in accordance with Fig. 4, subsequently stress relieved when required, and machined to required dimensions as shown in Figs. 5 and 6. Fig. 5a provides the dimensions of the jig used for bend tests.



Pass	Electrode	Amps	Volts	Travel Speed
1	1/4"	1100	37	12 in/min
2	1/4"	1300	37	8 in/min

Fig. 3 I Edge preparation and welding conditions for automatic submerged arc welds

Duplicate flat transverse reduced section tensile bars provided information regarding the strength of the welded joint, and also location of failure, i.e., in the plate and/or in the weld. Tensile test specimens were considered satisfactory, if, according to the Code, the

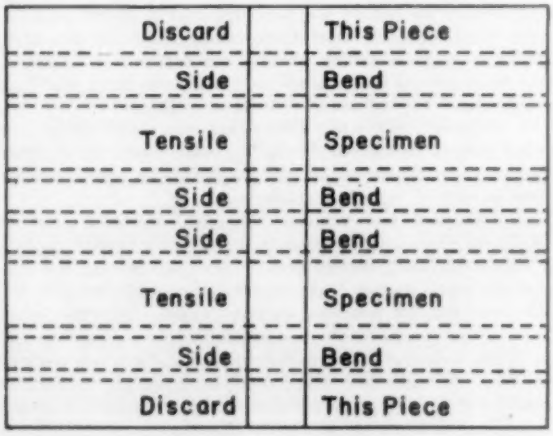


Fig. 4 Order of removal of test specimen from welded test plate (for plate over 3/4 in. thick)

tensile strength was not less than the minimum of the specified tensile range of the plate. The test was also considered satisfactory if the specimen failed in the base metal outside of the weld or fusion line at a value of not less than 95% of the specified minimum tensile strength of the base metal. Four transverse side bend specimens provided a criterion for judging weld joint ductility and soundness. Figure 7 is a photograph of a specimen partially bent. In the side-bend test according to the Code, a specimen is considered to have passed if, after bending 180 deg, no defect greater than $^1/_8$ in. in length is noted on the tension side. Cracks originating at the corners of the specimen are not considered, unless there is specific evidence that such cracks resulted from inclusions or other internal defects.

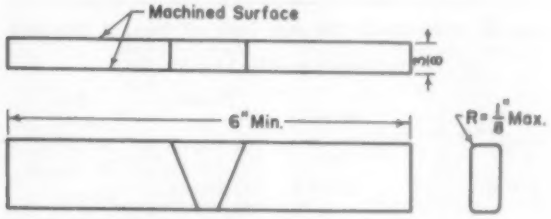


Fig. 5 Side-bend specimen

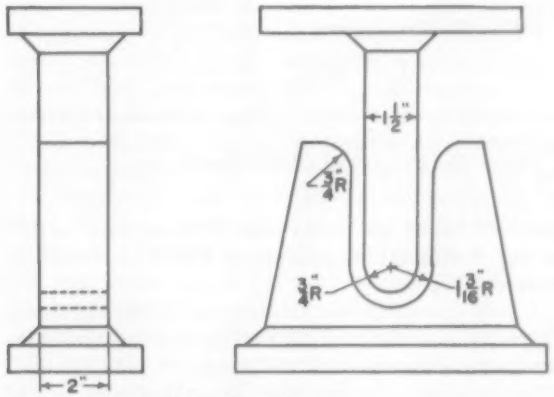


Fig. 5a Guided-bend-test jig

Materials

A. Steels

Three pairs of steels with minimum yield strengths of 50,000, 70,000 and 90,000 psi minimum, respectively, were selected for study. In the 50,000 psi minimum yield strength group, the materials selected were a Mn-Mo (ASTM A302 Gr.B) and a Mn-V-Ti steel, both supplied in the normalized condition. For the 70,000 psi minimum yield strength class, the steels chosen were a normalized and tempered Ni-Cu-Mo-V type and a hot-rolled plus stress-relieved Ni-Cu-Mo steel. In the 90,000 psi minimum yield strength class, a quenched plus tempered Mn-Cr-Ni-Mo-Cu-V steel, and a quenched plus tempered Mn-Mo (0.30% C) steel were studied.

A chemical analysis of the steels is shown in Table 1. Steels A and B are in the 50,000 psi minimum yield strength class, C and D are in the 70,000 psi minimum group, while steels E and F are in the 90,000 psi minimum yield strength class.

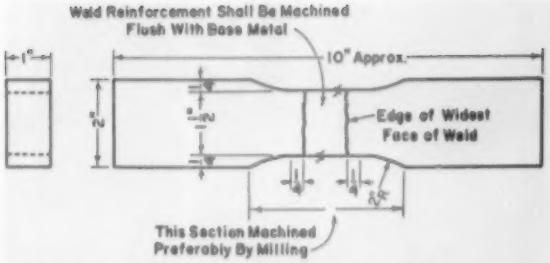

Weld Reinforcement Shall Be Machined Flush With Base Metal
1"
10" Approx.
Edge of Widest Face of Weld
This Section Machined Preferably By Milling

Fig. 6 Reduced-section tension specimen (plate)

B. Electrodes

Although a wide variety of electrodes is available to weld carbon and some low-alloy steels, the use of an electrode depositing weld metal differing in composition from that of the base material is not uncommon. As an example, the use of E7010, and/or E7020 electrodes, containing 0.5% Mo, is not unusual for welding A212 Gr.B steel, a carbon-silicon type. This difference between weld metal and base metal compositions positions persists to an even greater degree in welding of those high-strength steels under consideration here. One reason for the difference is the decision to limit qualification tests to present commercially available electrodes. In that connection, there is a very limited choice of compositions for tensile ranges over 100,000 psi. A second reason for unlike compositions between weld metal and base metal is that some low-alloy steels may contain an element which is not readily transferred through the arc. It is virtually impossible under such a condition, to match weld and plate composition even if it were desirable to do so. For no reason should the foregoing statements be considered as criticism of electrode manufacturers. It is realized that, heretofore, high-strength steels did not receive attention to the degree now being focused upon them. Furthermore, if standard electrode compositions, although differing from the steel analysis, perform suitably, there is little reason to develop electrodes of composition comparable to base metals, unless there

Table 1—Analysis of Materials

	Steel					
Element	*A*	*B*	*C*	*D*	*E*	*F*
C	0.17	0.18	0.10	0.15	0.14	0.30
Mn	1.30	1.03	0.54	0.68	0.93	1.54
Si	0.24	0.14	0.23	0.03	0.30	0.18
S	0.029	0.036	0.027	0.02	0.020	0.019
P	0.020	0.022	0.006	0.012	0.019	0.018
Cr	0.02	0.04	0.60	0.02	0.19	0.01
Ni	0.10	0.05	2.28	1.47	1.06	0.01
Cu	0.21	0.11	0.26	0.62	0.27	0.06
Mo	0.40	0.01	0.41	0.32	0.46	0.11
V	Nil	0.08	0.09	Nil	0.05	0.11
Ti	...	0.004	...	...	...	...
B	...	...	...	...	0.007	0.004
Al	0.025	0.013	0.058	0.04	0.063	0.033

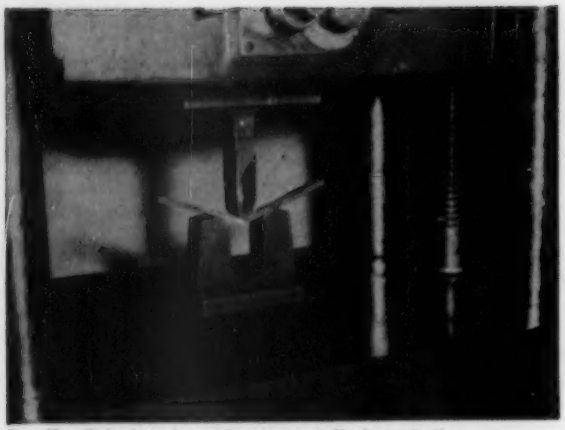


Fig. 7 Side-bend specimen partially bent in jig

are specific reasons for doing so.

Electrodes employed for welding the high-strength steels in this investigation were those recommended by the steel suppliers. Almost without exception the EXX15 or EXX16 type was specified, although in some cases the recommendations included other types in addition to the EXX15 or EXX16. For this study the EXX15 and EXX16 types were employed.

Manual Weld Results

50,000 Psi (Minimum) Yield Strength Steels

Steel A. The first of the two steels chosen in the 50,000 psi minimum yield strength level was a Mn-Mo steel produced to ASTM A302 Grade B specifications. This specification requires that the steel have a tensile range of 80,000–100,000 psi after normalizing. The mechanical properties of the material in the as-received (normalized) and in the as-received plus stress-relieved condition are shown in Table 2. It was necessary to determine the effect of stress relief on the properties of the plate since, according to Section VIII of the ASME Code for Unfired Pressure Vessels, a stress relief is mandatory for welded plate of the composition employed here. It may be observed from Table 2 that the properties were satisfactory for both conditions.

Results of the procedure qualification tests for Steel A using an E7016 electrode are shown in Table 3, whereas results obtained using E8016 (1% Ni) and E9015 (1.5% Mn–0.5% Mo) are shown in Table 4. All tests adequately met the requirements of the Code. A photograph of tested specimens taken from a plate welded in the horizontal position with E7016 electrodes is shown in Fig. 8.

It is of special interest to note that E7016 electrodes developed a tensile strength well beyond the level of its designated class, even for the stress-relieved condition. This disparity between the designated and actual

Table 2—Properties of Steel A as Determined from 0.505 In. Specimen Taken Perpendicular to Rolling Direction of Plate

	As-received	*Stress-relieved**
Tensile strength, psi	86,700	80,200
Yield strength, psi	60,200	59,200
Elongation, 2 in., %	26.6	26.5
Reduction of area, %	53.6	57.2

* 1150° F for 1 hr.

Table 3—Qualification Tests of Steel A* (Mn-Mo)

Electrode, E7016; preheat, none; postheat, 1150° F, 1 hr

Position	*Tensile, psi*	*Side Bend†*
Flat	83,000 (P)‡ 84,000 (P)	4—OK
Vertical	83,400 (W) 83,800 (W)	4—OK
Horizontal	83,600 (P) 84,400 (P)	4—OK
Overhead	87,400 (P) 85,900 (P&W)	4—OK

* No recommended welding procedure was available from steel supplier.

† Standard $1^1/_2$-in. ram.

‡ Key: P, plate failed; W, weld failed; OK, satisfactory.

Table 4—Additional Welding Tests of Steel A (Mn-Mo)

Preheat, none; position of welds, flat

Electrode	*Postheat*	*Tensile, psi*	*Side bend**
E7016	None	91,600 (W)†	2—Failed
		91,800 (W)	2—Passed
E7016	1150° F	83,000 (P) 84,000 (P)	4—OK
E8016 (Ni)	None	93,500 (P) 93,200 (P)	4—OK
E8016 (Ni)	1150° F	80,700 (P) 84,400 (P)	4—OK
E9015 (Mn-Mo)	None	93,600 (P) 91,000 (P)	4—OK
E9015 (Mn-Mo)	1150° F	85,400 (P) 84,900 (P)	4—OK

* Standard $1^1/_2$-in. ram.

† Key: (W) Weld failed; (P) plate failed.

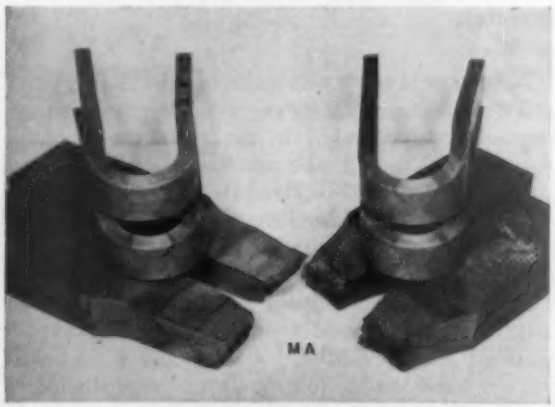


Fig. 8 Steel A—Manual weld. Horizontal position. No preheat. 1150° F postheat. E7016 electrode

Table 5—Analysis of Welds Made in Steel A

	E7016	E8016	E9015
C	0.07	0.07	0.06
Mn	0.62	0.73	1.55
Si	0.50	0.67	0.37
S	0.020	0.022	0.023
P	0.005	0.006	0.006
Mo	0.01	0.01	0.40
Ni	...	1.06	...

Table 6—Tensile Properties of E7016 and E8016 Weld Metal

Plate.....Steel A (Mn-Mo)
Plate thickness.....1 in.
Preheat.....None
Interpass temperature....100° F
Position of welding.....Flat

Electrode	Stress relief, ° F	Yield strength, psi	Tensile strength, psi	Elongation, 2 in., %	Reduction of area, %
E7016	None	69,400	79,600	29.7	66.4
E7016	1150	66,600	79,200	29.7	69.1
E8016	None	78,300	89,800	28.1	68.5
E8016	1150	76,400	88,700	28.1	67.5

strength was thought to have resulted from pick-up of alloying elements from the plate. However, an analysis of the weld metal, reported in Table 5, disclosed no unusual percentages of elements. The analysis, in fact, agreed closely with that of the electrode manufacturer. Moreover, all weld metal tensile tests, reported in Table 6, agreed with information published by the electrode supplier. While specimen geometry may be the underlying cause for the observed inequality in strength, tests must be conducted to corroborate such conjecture. In that connection, it is suggested that a flat transverse tensile bar and a round transverse tensile specimen be tested.

Steel B. The second steel of the 50,000 psi minimum yield strength group employed in procedure qualification tests was a Mn-V-Ti steel. Results for all position welds in both as-welded and stress-relieved conditions

Fig. 9 Steel B—Manual weld. Horizontal position. No preheat. 1150° F postheat. E7016 electrode

Fig. 10 Steel C—Manual weld. Horizontal position. No preheat. No postheat. E10016 (Ni-Mo-V) electrode

are shown in Table 7. It may be observed that all tests consistently met the requirements of the Code in the as-welded as well as the stress-relieved condition. Figure 9 shows a set of stress-relieved test specimens removed from a plate in the horizontal position.

70,000 Psi Minimum Yield Strength Steels

Steel C. The first steel in this group was a normalized and tempered Ni-Cu-Mo-V type. Mechanical properties of this type determined on duplicate 0.505-in. diam specimens (as-received), taken transverse to the direction of rolling, were as follows: tensile strength, 93,350 psi; yield strength, 77,850 psi; elongation (2 in.), 25.0%; reduction of area, 59.8%.

Results of tensile and bend tests made for this steel may be noted in Table 8. It is of interest to note that all requirements of the Code were met without stress relief. In this connection the recommendation of the steel supplier to forego stress relief may be due to the composition of electrode employed. The E10016 (Ni-Mo-V) composition is affected adversely by stress

Table 7—Qualification Tests of Steel B* (Mn-V-Ti)

Electrode, E7016; preheat, none

Position	Postheat, ° F	Tensile, psi	Side bend†
Flat	1150	79,600 (P)‡ 74,250 (P)	4—OK
Vertical	None	73,180 (P) 73,100 (P)	4—OK
Vertical	1150	70,800 (P) 72,600 (P)	4—OK
Horizontal	None	75,400 (P) 76,200 (P)	4—OK
Horizontal	1150	74,400 (P) 75,400 (P)	4—OK
Overhead	None	76,300 (P) 76,800 (P)	4—OK
Overhead	1150	74,600 (P) 75,300 (P)	4—OK

* Steel supplier's recommended procedure: Electrode, E70XX; preheat, 1¼ in. thick and over; postheat, only where impact is involved.
† Standard 1½-in. ram.
‡ Key: P, plate failed; OK, satisfactory.

Table 8—Qualification Tests of Steel C*

Electrode, E10016 (Ni-Mo-V); preheat, none; postheat, none

Position	Tensile, psi	Side bend†
Flat	100,350 (P)‡ 100,300 (P)	4—OK
Vertical	105,000 (P) 104,600 (P)	4—OK
Horizontal	103,400 (P) 103,600 (P)	4—OK
Overhead	102,700 (P) 102,500 (P)	4—OK

* Steel Supplier's Recommended Procedure: Electrode, E10016; preheat, 100 to 150° F; postheat, none.
† Standard $1^1/_2$-in. ram.
‡ Key: P, plate failed; OK, satisfactory.

Table 9—Mechanical Properties of E10016 Weld Metal

Plate.....Steel C
Plate thickness.....1 in.
Electrode.....E10016 (Ni-Mo-V)
Preheat.....None
Position.....Flat

Stress relief, ° F	Yield strength, psi	Tensile strength, psi	Elongation, 2 in., %	Reduction of area, %
None	93,000	99,800	21.05	55.7
1150	106,800	113,500	21.05	54.6
1150	105,000	111,800	21.05	54.2

relief,[9] i.e., its transition temperature is raised. However, to infer that some other composition of electrode, suitable for stress relief, could be employed for this steel is not justified without knowledge of the effect of a stress-relieving heat treatment upon base metal mechanical properties and transition temperature. Such information is presently being obtained by PVRC.

In connection with the E10016 electrodes employed in these tests, mechanical properties are listed in Table 9. The marked increase in yield and tensile strength as a result of stress relief may be noted.

Typical results of test specimens from a plate welded in the horizontal position may be observed in Fig. 10.

Steel D. The second steel in the 70,000 psi minimum yield strength group employed for procedure qualification tests was an hot-rolled and stress-relieved Ni-Cu-Mo steel. Mechanical properties of this steel (as-received) determined from duplicate 0.505-in. diam specimens taken perpendicular to the direction of rolling were as follows: tensile strength, 92,000 psi; yield strength, 75,100 psi; elongation (2 in.), 21.5%; reduction of area, 61.6%.

Results of tensile and bend tests, from assemblies welded with E9015 (Mn-Mo) electrodes followed by a stress relief treatment of 1 hr at 1100° F, are shown in Table 10. No difficulty, it can be noted, was encountered in meeting Code requirements. Figure 11 shows typical results of tests of a plate welded in the horizontal position.

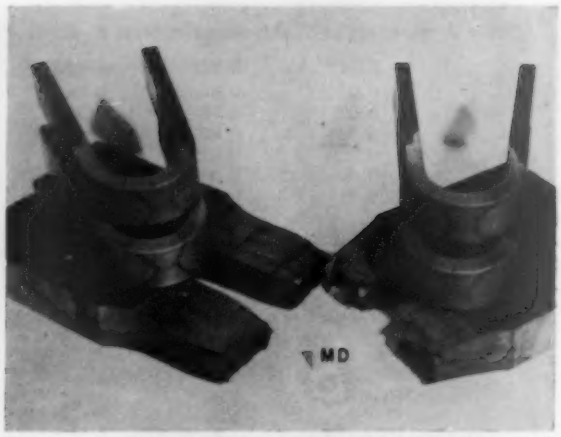


Fig. 11 Steel D—Manual weld. Horizontal position. No preheat. 1100° F postheat. E9015 (Mn-Mo) electrode

90,000 Psi Minimum Yield Strength Steels

Steel E. A quenched and tempered Mn-Cr-Ni-Cu-Mo-V steel was the first of two steels of 90,000 psi minimum yield strength chosen for procedure qualification. Mechanical properties of this steel (as-received) determined from duplicate 0.505-in. diam test bars taken transverse to rolling direction were as follows: tensile strength, 125,000 psi; yield strength, 116,000 psi; elongation (2 in.) 18.8%; reduction of area, 58.0%.

Results of procedure qualifications, made in all positions employing a Ni-Mo-V (E12015) electrode without preheat or postheat, are shown in Table 11. The results show that present Code requirements, for flat, vertical and horizontal position welds, were met satisfactorily. A photograph, Fig. 12, shows tested specimens removed from a plate welded in the horizontal position. In the overhead position, however, two side-bend specimens failed. A photograph, Fig. 13, shows the results of the four side bends tested from the overhead position weld. The testing jig was subsequently modified by increasing the radius of the male member from $^3/_4$ to $1^1/_4$ in., and the female member a corre-

Table 10—Qualification Tests of Steel D* (Ni-Cu-Mo)

Electrode, E9015 (Mn-Mo); preheat, none; postheat, 1100° F* 1 hr

Position	Tensile, psi	Side bend†
Flat	94,800 (HAZ)‡ 94,700 (P)	4—OK
Vertical	95,200 (P) 95,400 (P)	4—OK
Horizontal	96,700 (P) 95,700 (P)	4—OK
Overhead	97,800 (P) 97,400 (P)	4—OK

* Steel Supplier's Recommended Procedure: preheat, none; postheat, 1100° F, 1 hr.
† Standard $1^1/_2$-in. ram.
‡ Key: (HAZ) failed in heat-affected zone; (P) plate failed; (OK) satisfactory.

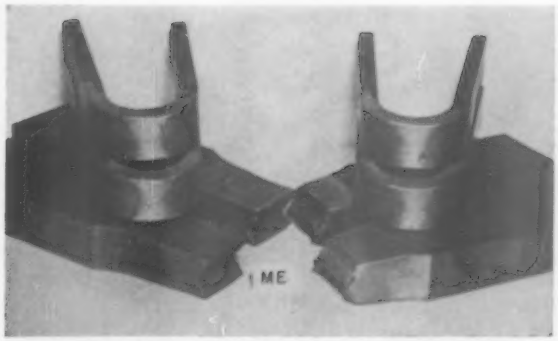


Fig. 12 Steel E—Manual weld. Horizontal position. No preheat. No postheat. E12015 (Ni-Mo-V) electrode

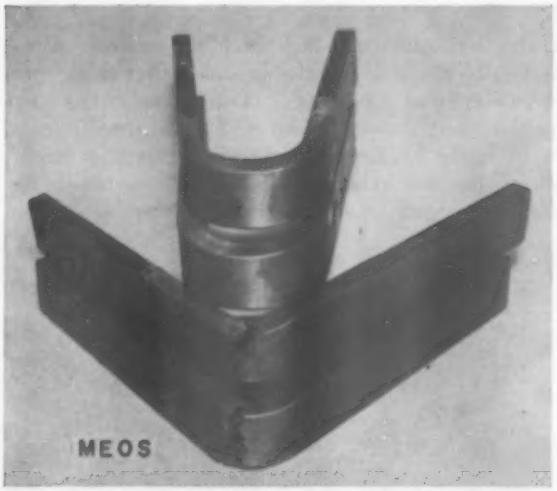


Fig. 13 Steel E—Manual weld. Overhead position. No preheat. No postheat. E12015 (Ni-Mo-V) electrode.

sponding amount. Four additional side-bend specimens were tested in the larger jig. Those additional specimens passed satisfactorily as may be noted in Fig. 14.

The use of an oversize plunger undoubtedly reduces the ductility requirement of the side-bend test and is a deviation from present code testing standards. The legitimacy of such a change is, of course, open to question. The legitimacy of an increase in plunger radius notwithstanding, a thought-provoking question of how much ductility is required of a welded joint to perform satisfactorily, is immediately suggested. In this connection, it would be of special interest if the past history of the side-bend test were made available.

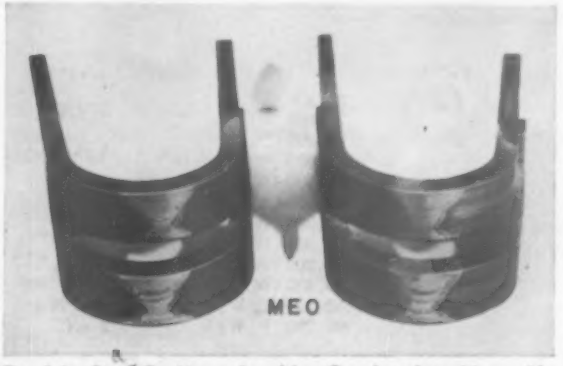


Fig. 14 Steel E—Manual weld. Overhead position. No preheat. No postheat. E12015(Ni-Mo-V) electrode. Specimens were tested using oversize ram

Table 11—Qualification Tests of Steel E* (Mn-Cr-Ni-Cu-Mo-V-B)

Electrode, E12015 (Ni-Mo-V); preheat, none; postheat, none

Position	*Tensile, psi*	*Side bend†*
Flat	122,200 (P&W)‡ 123,000 (W)	4—OK
Vertical	119,400 (W) 119,000 (W)	4—OK
Horizontal	123,600 (W) 123,500 (FL)	4—OK
Overhead	124,900 (P&W)	2—OK
	124,800 (P&W)	2—NG 4—OK using 2.5-in. ram

* Steel supplier's recommended procedure: Electrode, E12015; preheat, none; postheat, none.
† Standard 1½-in. ram unless otherwise indicated.
‡ Key: W, weld failed; P, plate failed; FL, fusion line failure; OK, satisfactory; NG, unsatisfactory.

Table 12—Qualification Tests of Steel F* (Mn-Mo)

Preheat, 200° F; postheat, none

Electrode	*Position*	*Tensile, psi*	*Side bend†*
E10016 (Ni-Mo-V)	Flat	115,100 (W)‡ 115,900 (W)	4—NG
E12015 (Ni-Mo-V)	Flat	120,000 (HAZ) 116,000 (HAZ)	4—OK
E12015 (Ni-Mo-V)	Vertical	117,000 (HAZ) 117,000 (HAZ)	4—NG
E12015 (Ni-Mo-V)	Horizontal	119,000 (P) 115,000 (P)	4—OK
E12015 (Ni-Mo-V)	Overhead	119,200 (HAZ) 115,900 (HAZ)	4—OK (2.5-in. ram)
E12015 (Ni-Mo-V)	Vertical Repeat Test	114,000 (P) 115,500 (P&W)	4—OK (2.5-in. ram)

* Steel supplier's recommended procedure: Electrode, E7016, E10016, E12015; preheat, 200° F; postheat, none.
† Standard 1½-in. ram unless otherwise indicated.
‡ Key: W, weld failed; P, plate failed; HAZ, heat-affected zone; NG, unsatisfactory; OK, satisfactory.

Steel F. The second steel in the 90,000 psi minimum yield strength group was a Mn-Mo (0.30% C) steel. Mechanical properties were as follows: tensile strength, 119,300 psi; yield strength 92,700 psi; elongation (2 in.) 16.5%; reduction of area, 45.5%.

Procedure qualification results may be noted in Table 12. It will be observed that with E10016 electrodes in the flat position and E12015 electrodes in the vertical position, satisfactory side bends could not be made with the standard jig. A view of typical failures may be noted in Fig. 15. When specimens from a plate

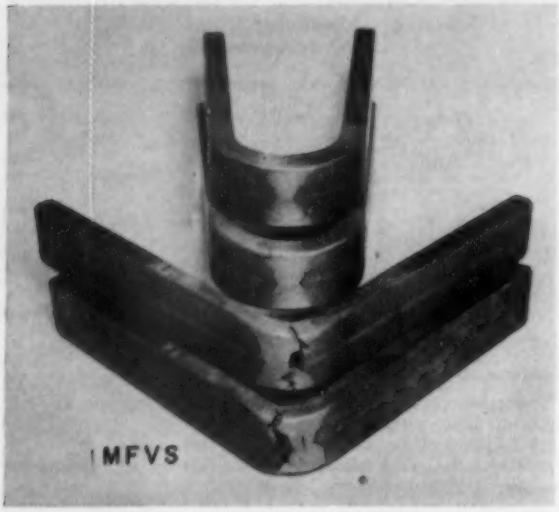


Fig. 15 Steel F—Manual weld. Vertical position. 200° F preheat. No postheat. E12015 (Ni-Mo-V) electrode. Specimens were tested using standard size ram

welded in the vertical position with E12015 electrodes, were subjected to bending in the oversize jig (2.5-in. ram), immediate success was obtained. A view of such specimens is shown in Fig. 16. Figure 17 is a photograph of specimens obtained from a plate welded in the horizontal position.

The difficulty which has been experienced in consistently meeting bend requirements for this material is similar to that reported for Steel E. The cure for the difficulty is also the same as for Steel E. It becomes quite evident, therefore, that if steels of 90,000 psi minimum yield strength are to be considered for pressure vessel use, serious consideration must be given to modifying the Code requirement of the side-bend test. In this connection a review of the past history and adoption of the present side-bend test is warranted.

Automatic Weld Results

A limited number of tests, intended to be of an exploratory nature only, were made using the automatic a-c submerged-melt welding process. Commercially available electrodes and melt compositions were employed throughout. Details concerning joint preparation, current, voltage and travel speed may be noted in Fig. 3. Details surrounding preheat, postheat, electrodes and welding melts, as well as results obtained therefrom, can be observed in Table 13.

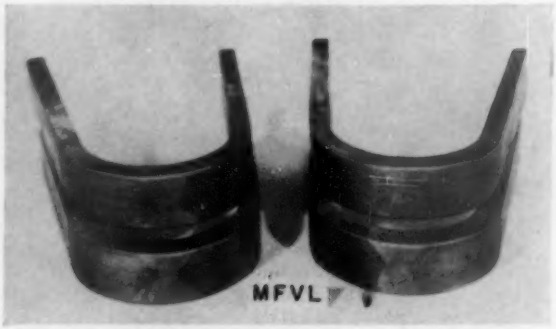


Fig. 16 Steel F—Manual weld. Vertical position. 200° F preheat. No postheat. E12015 (Ni-Mo-V) electrode. Specimens were tested using oversize ram

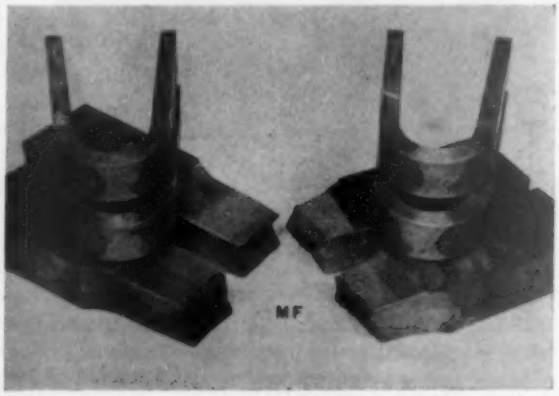


Fig. 17 Steel F—Manual weld. Horizontal position. 200° F preheat. No postheat. E12015 (Ni-Mo-V) electrode. Specimens were tested using standard size ram

Table 13—Two-Pass Automatic Submerged Melt Welds

Steel	Preheat, °F	SR, °F	Rod	Melt‡	Tensile, psi	Side bend*
A	No	1150	2% Mn-1/2% Mo	1	80,800 (P)† 79,600 (P)	4—OK
B	No	1150	2% Mn-1/2% Mo	2	74,900 (P) 75,000 (W)	4—OK
C	No	None	2% Mn-1/2% Mo	1	97,400 (W, FL) 97,200 (W, FL)	4—OK
D	No	1100	2% Mn-1/2% Mo	1	92,200 (W) 91,600 (W)	4—OK
E	No	None	Ni-Mo-V	1	108,300 (W) 109,800 (W)	4—OK
F	200	None	Ni-Mo-V	1	100,000 (P, W) 100,200 (P, W)	2—OK 2—NG

* Standard 1 1/2-in. ram unless otherwise indicated.
† Key: W, weld failed; P, plate failed; FL, fusion line failure; NG, not satisfactory. ‡ Melt 1, prefused, low-manganese welding composition. Melt 2, prefused, nonmanganese-bearing welding composition.

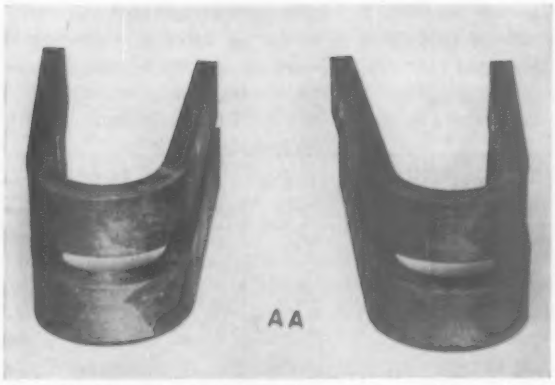


Fig. 18 Steel A—Submerged melt weld. No preheat. 1150° F postheat. 2% Mn – 0.5% Mo rod

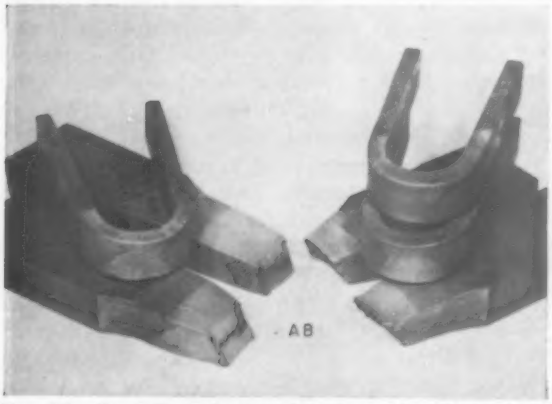


Fig. 19 Steel B—Submerged melt weld. No preheat. 1150° F postheat. 2% Mn – 0.5% Mo rod

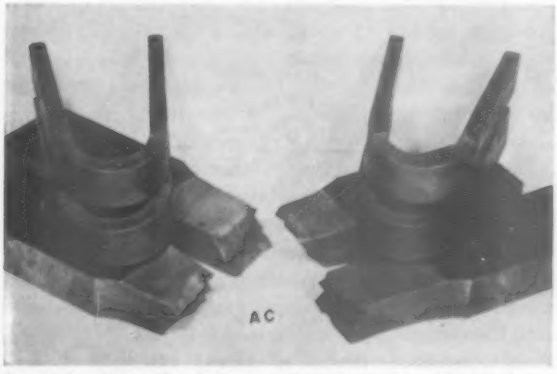


Fig. 20 Steel C—Submerged melt weld. No preheat. No postheat. 2% Mn – 0.5% Mo rod

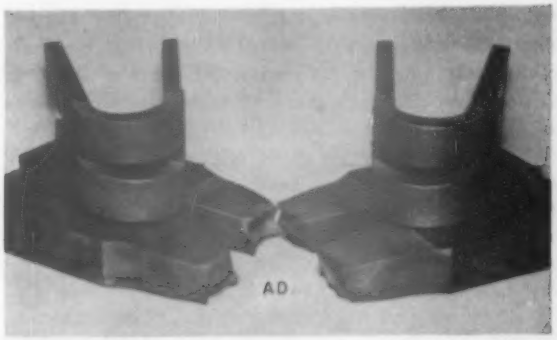


Fig. 21 Steel D—Submerged melt weld. No preheat. 1100° F postheat. 2% Mn – 0.5% Mo rod

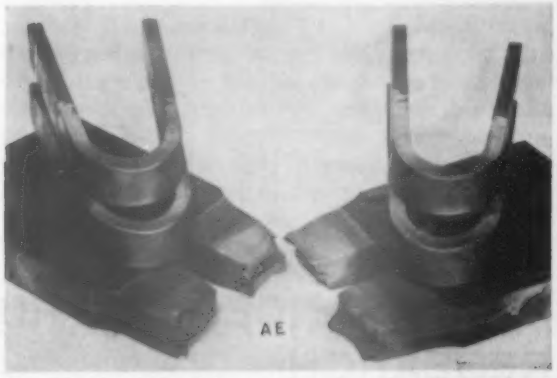


Fig. 22 Steel E—Submerged melt weld. No preheat. No postheat. Ni-Mo-V rod

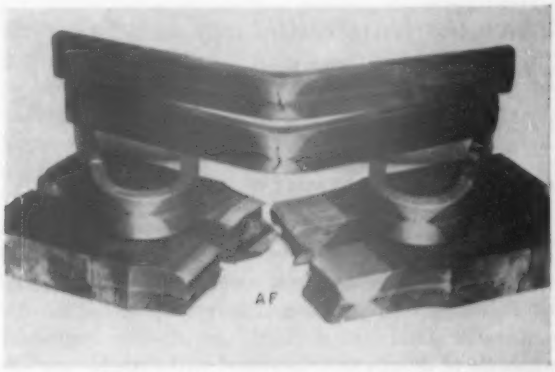


Fig. 23 Steel F—Submerged melt weld. 200° F preheat. No postheat. Ni-Mo-V rod

The results show that for Steel A the qualification was acceptable even though the strength of one tensile specimen was below the minimum of 80,000 psi specified for this steel. The Code provides that, if a specimen breaks in the parent plate at a value of not less than 95% of the minimum of the specified range, the specimen is considered to have passed. The results also indicate a tendency toward a slight lowering of the plate tensile strength. This reduction in strength may be due to the high energy input employed in making the test weld. A photograph of the side-bend specimens for this steel is shown in Fig. 18.

Figures 19, 20 and 21 show specimens tested from Steels B, C and D, respectively. All three steels appear to be readily weldable by the submerged-melt process.

For Steel E, it is of interest to note that the side-bend specimens consistently met the full jig bend using a standard plunger. However, the tensile specimens failed consistently in the weld at an ultimate strength

value considerably below that of the plate. Further study of this process of welding, involving electrode composition and/or multipass technique of welding, is desirable. A photograph of tested specimens may be seen in Fig. 22.

For automatic welds made in Steel F, the same inconsistency in meeting bend requirements, reported for manual welds, was evident (Fig. 23). In addition, the ultimate strength was reduced perceptibly, as was the case for Steel E. It is quite apparent that further study of this steel, in so far as automatic welding is concerned, is required before any recommendations can be made.

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IMPORTANCE OF STRUCTURAL STEEL RESEARCH

An indication of the type of research which the Universities can do which would be of benefit to the Structural Steel Industry

By NORMAN W. RIMMER

I would like to talk to you about the importance of structural steel research and the relationship between industrial research and university research. An aggressive industry demands constantly improved methods of design and improved materials for its application and use. These demands are met basically through the engineering sciences. Material requirements cause engineering scientists to explore and exploit the resources and forces of nature which in time may lead to the exhaustion of specific resources and the development of entirely new ones. This causes evolutionary changes to take place through the resourcefulness, initiative and industry of man aided by science.

Our frontiers are advanced principally through research. We are concerned with a segment of this frontier. Through the tools of engineering science our specific purpose is to advance the structural steel industry not only for its own benefit but for society as a whole. Our research program must be kept in balance with the needs of the times if we are to fulfill our obligations to society. I want to discuss with you the importance of research in the structural field and the need for balance in this research. The basic long range needs of the structural steel industry are to reduce costs, to improve quality and to expand markets. The sound approach to every one of these needs is through research and education.

It should be the function of the university research group to do things that the manufacturing industry cannot do for themselves. This brings up the question of which types of research should be done by the university and which types should be done by industry.

Norman W. Rimmer is Engineer-in-Charge, Structural Design Section, Butler Manufacturing Co., Kansas City, Mo.

Presented at the University Research Conference held in Chicago, Ill., Nov. 3, 1954.

Broadly speaking, research can be divided in two general groups. One being fundamental research and the other applied research. Fundamental research is the area of investigation where great individuals without specific objectives or thought of economic implications conceive and discover new relationships in nature. Men who make such contributions to knowledge are rare but the value of their contributions is great and essential for progress. Fundamental, by definition, means: foundation, groundwork, indispensable or primary. It constitutes the development of essential knowledge. Unless this area of research is kept alive and active, sources of knowledge dry up and new applications cease. It is to be expected that a large portion of industrial research must be applied research since industry is concerned primarily with the development of products to sell in competitive markets. It does not follow that industry should have the exclusive responsibility for all applied research but with the rapid development of competent industrial engineering and research staffs, industries are now equipped to do much more of the applied research.

We should recognize that the area of applied research is a broad one. It is of great importance to industry, and it seems logical that industry should prepare to assume expanding responsibilities in it. Industry is investing heavily in research simply because it has found that research is essential to progress. Yes—even to existence in our competitive business economy. It is now generally recognized that a sound research and development program well coordinated with the business interests of the company is a form of profit insurance and a continuing operating necessity.

There are limits to the scope of research that can profitably be carried out in industrial organizations. It would be unrealistic to expect an industrial laboratory to carry out an extended program of pure or fundamental research in fields not even remotely related to the interest of the company and it is likewise unrealistic to expect an industry to bear the cost of fundamental research when this company's competitors can take advantage of this research work without sharing any part of the expense. This would place the industry doing research at a disadvantage instead of giving an advantage to the company as would be normally expected from research activites. Most industrial research work is necessarily devoted primarily to applied research aimed at the solution of problems directly related to a business interest. However, industrial research directors and industrial management generally realize that their applied research programs must feed on new knowledge coming out of basic and fundamental research at the universities. Without a continuing supply of this essential raw material, our industrial research programs will surely and steadily starve.

Industrial leaders are giving an increasing amount of recognition to this fact and are supporting this research through cooperation with such organizations as the Welding Research Council which in turn supports fundamental research at the university. Through the cooperation of industry in this manner, it is possible to spread the cost of the fundamental research to all industry and also serves as a guide through polls taken by the council to determine the projects where further research would be of benefit to the majority of industry.

Steel is one of the most adaptable materials that can be used as a building material. Industries promoting the use of other types of building materials recognize the inherent advantages of structural steel and have inaugurated programs to bring about development in their materials that will offset the advantage that the structural steel industry has held for so many years. It is imperative that the structural steel industry unite in sponsoring an aggressive fundamental research program. Based on my experience with the Butler Manufacturing Co., which is one of the largest manufacturers of pre-engineered rigid frame buildings for industrial and commercial use, I would like to point out a few places where we feel that further fundamental research would be justified. We believe high-strength steel, when used in welded tapering rigid frame members, could be used to good advantage when deflection is not a primary consideration providing proper width-thickness ratios and buckling formulas can be established for compression flanges. We further believe that the welding of these built-up tapering sections with the use of continuous automatic fillet welds—on one side only—should be explored and promoted when shear stresses permit. The increase of the depth of penetration by the submerged arc process either semiautomatic or automatic, results in a fillet weld having a throat depth equal to or even greater than the leg dimension of the fillet. Using the manual process, the throat depth is only 0.707 of the fillet leg due to the limitations of this process. A great deal of time could profitably be spent in setting up design criteria for limit design which requires certain points on the structure to act as a plastic hinge without being affected by local wrinkling or buckling.

While the development of new and fundamental ideas are of prime importance, we should not overlook the fact that selling these ideas to the engineers and architects throughout the country is also important. The universities can play a leading role in this by introducing new ideas through their publications. This will bring the new ideas to the immediate attention of all engineers and architects as well as the building code authorities. The classroom can also be used as a sales medium by training future engineers and architects in the use of these ideas.

As a closing thought, I would like to say that research many times stops short of the point where the new idea can be useful commercially. It is very important that the basic or fundamental research be carried to a point that it can be used by the design engineer. The research report should include all of the fundamental information and conditions of the test, and also adequately evaluate the data presented so that the design engineer can readily apply the conclusions to his particular design problem.

UNIVERSITY RESEARCH COMMITTEE

The University Research Committee stimulates welding research among the leading universities of the United States and Canada. Such research work has many advantages, of which the following are merely typical examples:

1. It brings to the attention of some of the foremost scientists in this country the need for research work and clear thinking on some of the most complex problems of metallurgy, plasticity, physics and other branches of science involved in many of the welding problems.
2. It provides for the solution of some of these complex problems at reasonable cost.
3. It serves as a training center for young engineers and scientists in the problems of welding. These young men are later utilized by the welding and allied industries.

The method of operation of the University Research Committee is fairly simple and involves a number of important steps, of which the following are the most significant:

1. Once a year the University Research Committee holds a conference at the same time and place as the National Metal Congress and Exposition. It invites to these conferences all professors who have indicated an interest in welding research matters, and makes available a sum of approximately $1000 to defray the railroad and pullman expenses of the professors attending the conference, with a maximum upper limit of $50 to any one professor.
2. Once every two years the University Research Committee compiles a List of Research Problems which need solution, and which can be most readily handled at a university research laboratory. This list of problems is sent to all engineering schools of the country with an appropriate letter.
3. If some professor, or university, indicates an interest in a specific problem, the Committee stands ready to assist in the formulation of such problems, and in supplying bibliographical references. In many cases it stands ready also to supply specimens and small grants-in-aid.
4. It establishes fellowships on worth-while projects sometimes under the auspices of the University Research Committee, as mentioned above, or under a Project Committee of the Council which is closely affiliated with the work, or in the name of a contributing company.
5. It provides for periodic visits to these laboratories by responsible representatives of the University Research Committee.
6. It provides a mechanism whereby the results of the research work can be presented before the Annual Meetings of appropriate societies, and published in an internationally recognized scientific or engineering publication.
7. It places all University Research workers on a mailing list to receive all of the reports of the Council.

A revolving fixture holds this tubular steel chair-desk while the weldor brazes the joints with ANACONDA-997 (Low Fuming) Bronze Welding Rod. Heywood-Wakefield Company began producing welded steel tubing back in 1910. Today, they are leading manufacturers of tubular steel schoolroom furniture, bus, subway, railway car and theater seating.

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It's not only a fast job . . . it's a *good* job. The credit goes to Heywood-Wakefield engineers for their time-saving fixtures; to the weldor for his skill, and to the ANACONDA-997 rods he uses. Heywood-Wakefield prefers these rods because the finished welds are very strong, and they don't require special cleaning before painting. They're degreased, wire brushed . . . then painted. That's all.

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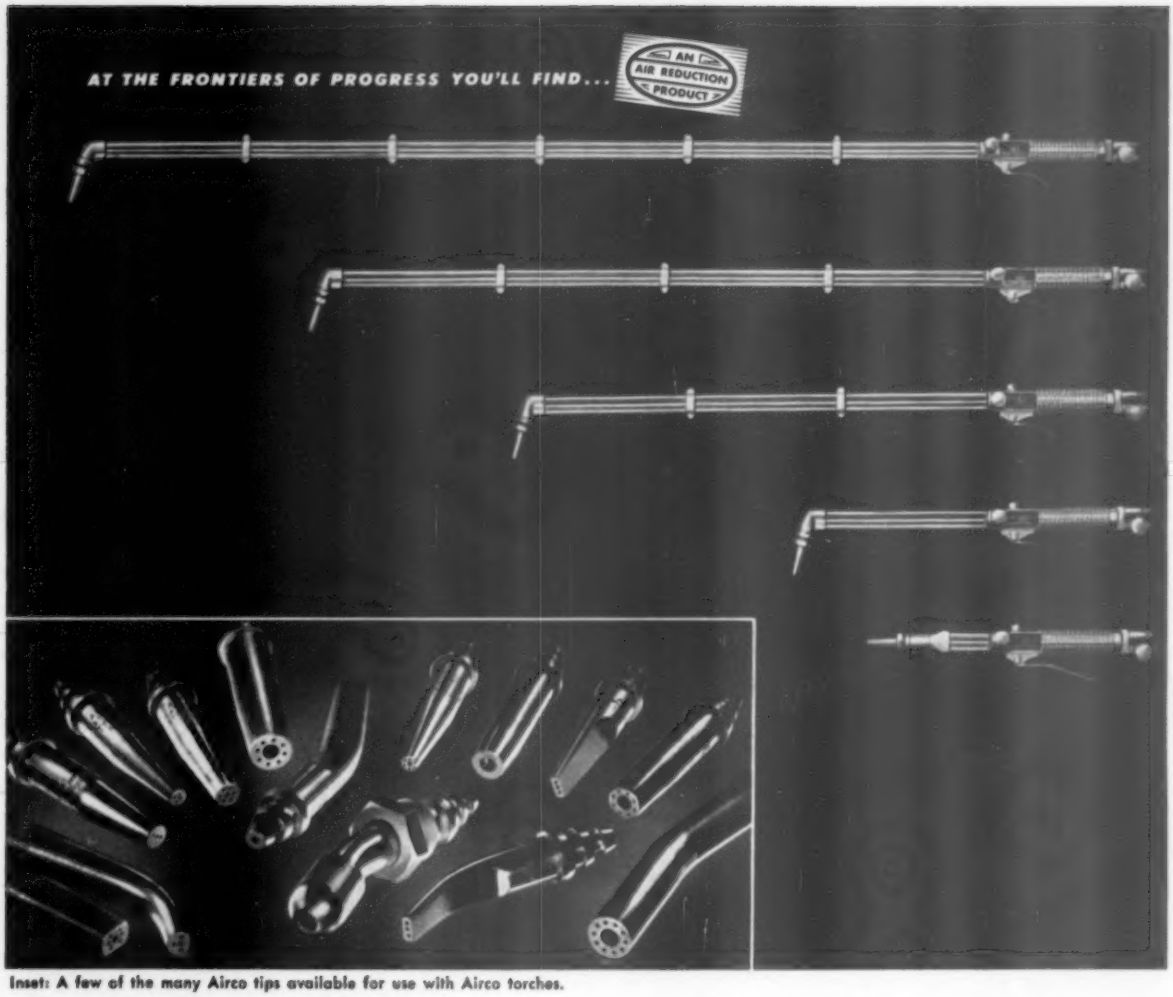

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